Citico Creek Watershed Characterization and Simulation Report

City of Chattanooga
Water Quality Management
Department of Public Works – Engineering

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Executive Summary

Citico Creek Watershed contains 2,530 acres of which urban structures such as residential, commercial and industrial properties are the primary land uses. This creek is a runoff and spring-fed waterway that is fully contained in City of Chattanooga jurisdictional boundaries. Past and on-going monitoring conducted by the City of Chattanooga show consistently high pathogen levels throughout Citico Creek. Fecal coliform and *Escherichia coli* counts measured at ten sampling sites along the creek have been as high as 83,000 and 44,000 cfu $100mL^{-1}$, respectively. For these reasons, segments of the primary stream running through the watershed are categorized as only partially supporting their designated uses according to the 2006 (and 2008 draft) Tennessee 303(d) list of impaired waterways prepared by the Tennessee Department of Environment and Conservation. The 2006 Tennessee 303(d) list also identifies low dissolved oxygen, nutrients (phosphorus), and habitat loss due to alteration in streamside cover as medium priorities. This document identifies pollutant sources such as Municipal Separate Storm Sewer System (MS4) discharges, hydromodification, and collection system failures.

The City of Chattanooga, as the owner and operator of the MS4, is authorized to discharge stormwater runoff in accordance with the State of Tennessee under the National Pollutant Discharge Elimination System (NPDES) and all elements and programs listed within. Under this permit, the City of Chattanooga is required to develop a comprehensive Watershed Characterization Report and standard reporting system for select waterways for which they have jurisdiction. Additionally, the city is required to perform hydrologic and pollutant loading modeling for select waterways and watersheds for which they have jurisdiction.

The planning area lies within the Ridge-and-Valley ecoregion of east Tennessee with relatively homogenous soils and soil properties. The area is highly urbanized, with nearly one half of the catchment classified as residential land. The watershed contains a great deal of supporting stormwater drainage and sanitary sewer infrastructure, both with substantial structural integrity issues. As such, many illicit discharges have been detected in the area through the various Water Quality field inspection programs. The Sewer Lateral Assessment Program has identified 777 failing sanitary infrastructure problems, with 606 of these repaired (78%). Additionally, Water Quality personnel have inventoried and evaluated nearly 60,000 feet of the waterway to document critical erosion areas. From these analyses it is suggested that increased canopy cover, buffer width, and cobble along the streambed improve overall stream corridor condition.

Surface waters in this watershed have been, and continue to be monitored by the City of Chattanooga by means of monthly dry- and wet-weather outfall inspections. General results from the City of Chattanooga's monitoring program indicate that Citico Creek is a poorly-oxygenated waterway with somewhat alkaline water, at a fairly stable water temperature, with moderately conductive water. Supplemental water quality monitoring began in 2007 to provide additional pathogen data for watershed assessments and characterization. Many of the individual water quality samples collected Autumn 2007 contained low levels of *E. coli* (42 out of 82 were below the state threshold of 941 cfu/100ml). However, during and immediately following the rain event, all of the sites exhibited high pathogen concentrations, suggesting flow related trends.

Additional monitoring was conducted in Winter 2008 with results following the same trend over time, with minimal deviation from one another. The range in concentrations was minimal for both site and sample date. A noted increase in pathogen counts was observed following a rain event, further supporting local precipitation-induced or flow-related *E. coli* trends.

A pathogen (bacteria) model was then employed to estimate bacteria concentrations and suspect sources following generally accepted theoretical equations. Data collected from Water Quality Program initiatives and monitoring programs were used as model inputs along with general and specific parameters of geology, hydrology and land use. Land uses identified and classified as high-density residential produced the greatest estimated pathogen concentration, likely stemming from failing private sanitary sewer lines, compromised city-owned main sewer lines, and any associated domesticated animal waste.

A similar water quality modeling exercise for sediment load was performed, with the generally accepted theory that pollutant loads may be estimated as a function of land use, basin acreage, rainfall, runoff, proximity to the channel, and pollutant concentration. Erosion estimates from the visual stream surveys were also input into the sediment model as real, absolute data. Total sediment load for the planning area is estimated at 1,460 tons per year, or 1,154 lbs/ac/yr. Through model calibration, this value roughly equals the loading rate of 1,156 lbs/ac/yr as defined by the TMDL for Siltation.

The present document serves as a first step in the comprehensive watershed management process for Citico Creek Watershed by characterizing watershed condition, identifying critical areas, prioritizing suspect pollutant sources, and estimating pollutant loads and concentrations. As this Watershed Characterization Report will ultimately serve as a foundation for a watershed-specific management plan, such identification, quantification, and qualification of such patterns and processes is paramount. This Watershed Characterization and Simulation Report illustrates the importance of developing an effective and integrated land management and monitoring approach for community stakeholders, which include local land owners, communities, authorities and resource managers, as they are required to make coherent, informed decisions regarding land resources and their future.

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BMP – Best Management Practice
BSLC – Bacteria Source Load Calculator
DO – Dissolved Oxygen
EMC – Event Mean Concentration
EPA – Environmental Protection Agency
GIS – Geographic Information System
HUC – Hydrologic Unit Code
IDDE – Illicit Discharge Detection and Elimination
IDP – Illicit Discharge Potential
LID – Low Impact Development
MS4 – Municipal Separate Storm Sewer System
NCDC – National Climate Data Center
NOAA – National Oceanic and Atmospheric Administration
NPDES – National Pollutant Discharge Elimination System
NRCS – National Resource Conservation Service
RMCF – Ready-Mix Concrete Facility
ROW – Right of Way
RPA – Chattanooga-Hamilton County Regional Planning Agency
RUSLE – Revised Universal Soil Loss Equation
SCORE – Stream Corridor Evaluation
SDR – Sediment Delivery Ratio
SEP – Supplemental Environmental Project
SLAP – Sewer Lateral Assessment Program
SSO – Sanitary Sewer Overflow
STEPL – Spreadsheet Tool for Estimating Pollutant Load
SWPPP – Stormwater Pollution Prevention Plan
TDEC – Tennessee Department of Environment and Conservation
TMDL – Total Maximum Daily Load
TMSP – Tennessee Multi-Sector General Permit
TVA – Tennessee Valley Authority
TWRA – Tennessee Wildlife Resource Agency
USDA – US Department of Agriculture
USGS – US Geologic Survey
USLE – Universal Soil Loss Equation
WPA – Works Progress Administration
WWTF – Waste Water Treatment Facility

1.0 Introduction

The deleterious effects of urbanization on water quality and quantity are evident across many parts of Tennessee and the region. The impact of urbanization on water resources is typically reflected in the alteration of the natural hydrological systems in terms of increasing the runoff rate and volume and decreasing infiltration, ground water recharge, and base flow. Concerns about these environmental impacts as well as other negative social and economic effects of urban sprawl have resulted in a widespread movement toward intelligent, planned forms of development, referred to as smart growth. To meet the needs of such development, the focus of hydrologic research and monitoring must be adjusted from simply identifying and quantifying the impact of land use change towards reducing the impact.

Urbanization is not a single condition or trend but rather a collection of actions that leads to recognizable landscape forms and, in turn, to changes in stream condition. In most urban areas, impervious surface area increases, leading to decreases in infiltration and increases in the rate and volume of surface runoff. Urban runoff containing common urban and residential pollutants can contribute to declines in biotic species richness of urban waterways, including fish populations. This cumulative process is reported to adversely impact the physical (sedimentation), chemical (eutrophication), and biological (benthic) characteristics of city and state waters.

Concern about the effects of urbanization on stream ecosystem functioning has encouraged efforts to understand and manage urban development at the national, state, and city levels, as well as motivated academic research efforts and grassroots environmental groups. This academic and planning concern has led to the question of what is the best possible condition for urban streams, for which no definitive answer has been provided. This focus has however promoted and fostered the utility of watershed management, by acknowledging that the attainment of effective, successful land and water management can only be assured with the integration of ecological, social, and economic approaches to environmental management problems. The watershed approach to land and water management is based on the concept that many water quality problems likely stem from adjacent land covers and uses and are best addressed at the watershed level.

Societal concerns about human effects on the environment are embodied in a variety of legislative mandates, as reflected in the Clean Water Act of 1972 (and as amended, US Code title 33, section 1251-1387). The objective of this act is to “restore and maintain the chemical, physical and biological integrity of (the) Nation’s water’ (US Code title 33, chapter 26, subchapter 1, section 1251a). While much of this mandate has successfully addressed point sources of pollution, a new emphasis is being placed on nonpoint sources. With increasing urban populations and demands for freshwater, the number and magnitude of nonpoint source stressors will continue to grow at the expense of the structure and ecological function of watersheds.

Local governments are required to address urban water quality through the National Pollutant Discharge Elimination System (NPDES) directed under the US Environmental Protection Agency (EPA). Under permits that EPA and individual states issue through this program, local jurisdictions must meet certain requirements in a certain timeframe to implement stormwater management programs to reduce contaminants in stormwater to the “maximum extent practicable.” The three primary mechanisms used in these NPDES programs include:

- efforts to characterize stormwater runoff;
- efforts aimed at reducing pollutants in stormwater runoff; and
- reporting program activities, including monitoring results.

The present document specifically addresses the first activity of characterizing the watershed and associated stormwater pollutants. For reasons introduced below, Citico Creek Watershed will serve as a model city watershed for characterization and modeling. This will help facilitate additional NPDES related activities for the City of Chattanooga, including appropriate watershed management to reduce urban runoff and associated stormwater pollutants.

1.1 Background

Mechanisms have been developed to restore select waterways and watersheds through local accountability, management, planning, and restoration. In Tennessee, The Division of Water Pollution Control of the Department of Environment and Conservation (TDEC) is responsible for administration of the Tennessee Water Quality Control Act of 1977 (T.C.A. 69-3-101). Surface waters classified as impaired, not meeting water quality standards, and/or failing to meet one or all of their intended uses, must be listed under Section 303(d) of the Clean Water Act and the Water Quality Planning and Management regulation of 40 CFR Part 130. The (Draft) 2008 303(d) List for Tennessee identifies nearly 1,250 stream reaches as impaired; or 20,000 out of 60,000 linear miles of state waterways.

TDEC Water Pollution Division utilizes all water quality data submitted to properly assess stream reaches. For example, the 2006 303(d) list considered data from US Army Corps of Engineers (USACE), Tennessee Valley Authority (TVA), US Geologic Survey (USGS), Tennessee Wildlife Resources Agency (TWRA), as well as TDEC field offices, and local jurisdictions. Impaired streams listed in this document must subsequently have some sort of restoration mechanism specified, such as a total maximum daily load (TMDL) document. A TMDL is a study that 1) quantifies the amount of a pollutant in a stream, 2) identifies the sources of the pollutant, and perhaps most importantly 3) recommends regulatory or other actions that may need to be taken in order for the stream to cease being impaired or polluted.

Several impacted waterways within the City of Chattanooga are noted on the 2006 Tennessee 303(d) list (TDEC 2006a) and the Draft 2008 303(d) list. Citico Creek, located within the center of the city (Figure 1.1), is currently listed on this list of impaired streams. The 2006 303(d) list for the Lower Tennessee River Watershed (HUC TN06020001), the waterbody into which Citico Creek deposits, cites 7.4 river miles as impaired, due to *Escherichia coli*, nutrients (phosphorus), low dissolved oxygen, and siltation leading to loss of biological integrity and habitat alteration (TDEC 2006a). This waterway has been listed as impaired by the state since 2002 (TDEC 2004a). This document, along with supporting pathogen and siltation TMDLs (TDEC 2006b, c), identify pollutant sources such as Municipal Separate Storm Sewer System (MS4) discharge, collection system failure, and hydromodification.

The City of Chattanooga, as the owner and operator of the MS4, is authorized to discharge stormwater runoff in accordance with the State of Tennessee under NPDES permit number TNS068063, and all elements and programs listed within. Under this permitting document, the City of Chattanooga is required to develop a comprehensive Watershed Characterization Report and standard reporting system for select waterways for which they have jurisdiction. Additionally, the permittee is required to perform hydrologic and pollutant loading modeling for select waterways and watersheds for which they have jurisdiction. By characterizing watershed condition, identifying critical areas, prioritizing suspect pollutant sources, and estimating pollutant loads and concentrations, the present document will serve to satisfy NPDES permit Section V.C. for the City of Chattanooga, as well as serve as a tool for future watershed planning, resource allocation, and water quality management purposes.

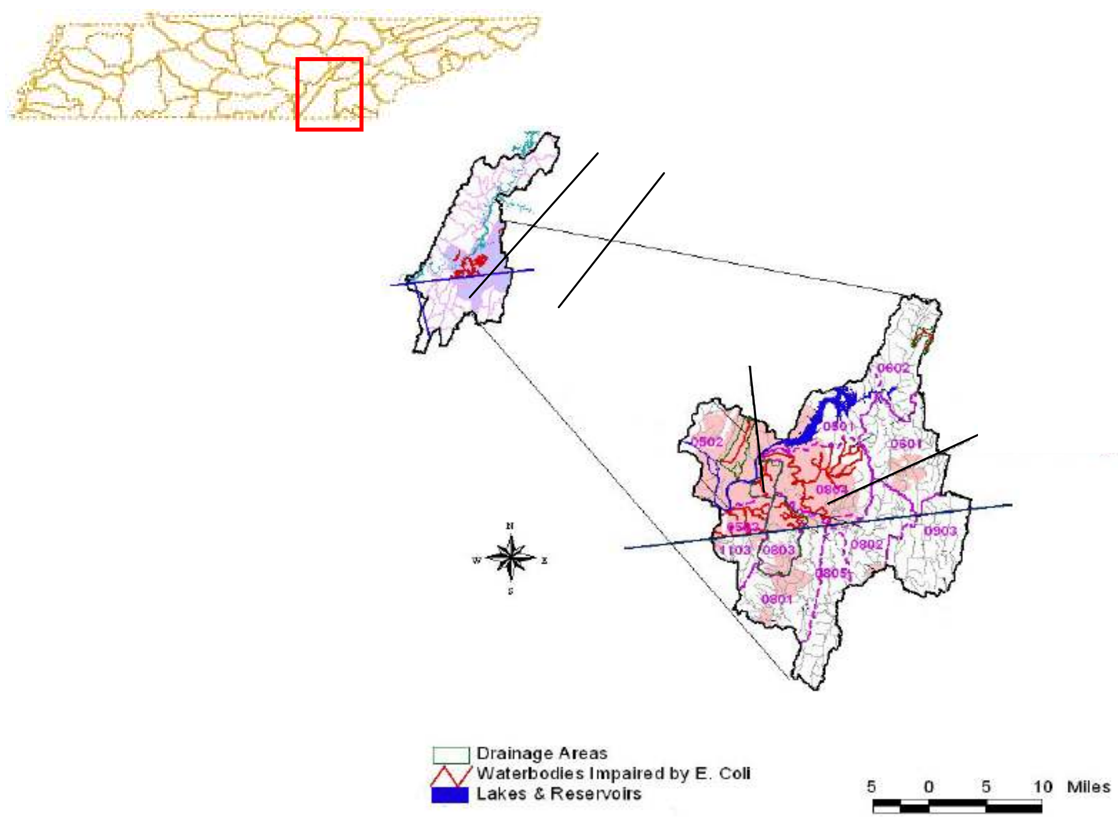

Figure 1.1. Map of Lower Tennessee River Watershed, location of impaired waterways as designated by the state, and Citico Creek; modified from TDEC 2006b.

1.2 Planning Area

Citico Creek Watershed (HUC TN060200011240) is classified as a third-order stream, with several unnamed tributaries converging into one main channel near the outfall in to the Tennessee River. The creek drains approximately 2,530 acres into the river, and is the only watershed fully contained within Chattanooga city limits (Figure 1.2). Citico Creek is fed by a series of springs nested along Missionary Ridge which runs north-south through the city. The 12.49 mile creek then flows west through neighborhoods, industrial and commercial facilities, and a major rail yard. As a result of this heavy urban land use and impervious cover, water quality in Citico Creek has been severely impacted.

Past and on-going monitoring conducted by the City of Chattanooga shows consistently high pathogen levels throughout Citico Creek. Fecal coliform and *Escherichia coli* counts measured at ten sampling sites along the creek have been as high as 83,000 and 44,000 cfu $100mL^{-1}$, respectively. For these reasons, segments of the primary stream running through the watershed are categorized as only partially supporting their designated uses according to the 2006 (and 2008 draft) Tennessee 303(d) list of impaired waterways prepared by the Tennessee Department of Environment and Conservation. The 2006 Tennessee 303(d) list also identifies low dissolved oxygen, nutrients (phosphorus), and habitat loss due to alteration in streamside cover as medium priorities. This document identifies pollutant sources such as Municipal Separate Storm Sewer System (MS4) discharges, hydromodification, and collection system failures.

Citico Creek Watershed lies within the Ridge-and-Valley physiographic system that is indicative, or occupies much of the eastern United States from central Mississippi to southern New York, along the Appalachian Mountain chain. Soils and bedrock in this region are some of the oldest in the state, and are generally deep with moderate to high permeability. As with most of the City of Chattanooga, the watershed occupies the low-lying valleys of this system, with elevations ranging from 1090 ft. at source springs to approximately 640 ft. at the Tennessee River outfall.

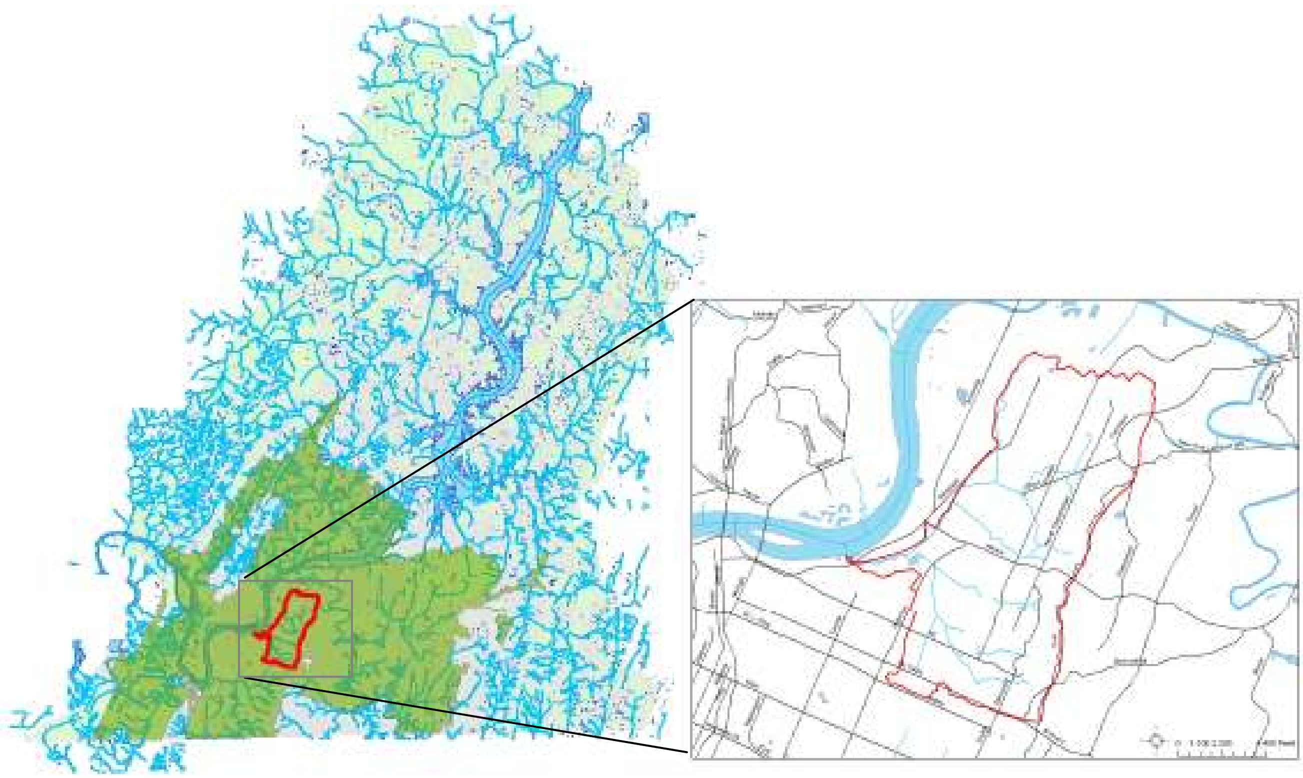

Figure 1.2. Location and delineation of Citico Creek Watershed (red, and inset), nested within Hamilton County and City of Chattanooga (in green).

1.3 Pollutant Modeling Approach

There has been a steady shift towards modeling and model-based approaches as primary methods of quantifying watershed-wide pollutant sources, loads, and concentrations, as well as best management practices (BMP) effectiveness. To meet this demand, surface water quality models have been developed as mathematical or theoretical descriptions of ecologic and hydrologic processes. The advantages of using models include: 1) multiple BMPs can be studied simultaneously; 2) the impacts of individual BMPs can be determined while also determining the effects of BMP combinations; 3) location- and time-specific responses can be obtained; 4) modeling offers a practical means of analyzing various "what-if" management scenarios; and perhaps most beneficially 5) models offer relatively rapid and inexpensive assessments of current and projected stream and land condition.

In this context, we propose an integrated, comprehensive, and collaborative approach of watershed management including the use of local knowledge, community partnerships, past and recent water quality monitoring data, GIS and remote sensing technology, and biogeochemical and bacteria flux models to develop sound and defensible strategies for stormwater and watershed management. Such analyses will also facilitate informed and effective decision making and policy planning.

The transport pathways and fate of naturally occurring constituents, such as solids and nutrients, and contaminants in a watershed are generally driven by complex interactions of precipitation, land uses, urban runoff, subsurface and surface water transport, stormwater inputs, kinetic transformations, and biological process in the water column and sediment bed. Mathematical models designed to represent the transport pathways and fate of contaminants in the aquatic environment serve as powerful tools in understanding, and differentiating the relative significance of natural processes and human activities on trends in water quality and resources. Models may be used to support the development of management plans, such as remediation of contaminated sites or best management plans for agricultural or construction operations.

Models of sediment transport, contaminant transport and fate, and contaminant bioaccumulation may be used to provide technical guidance needed for remedial action decisions for the improvement of water quality. Surface water models are often defined by the open boundaries of the physical domain and the corresponding specification of terms in the model equations that describe pollutant loads, physical transport processes and kinetic interactions as either externally provided model input, or internal algorithms calculated by model formulations. These inputs are modified by area, land use, imperviousness, slope, and soil properties, among others. Employing a relatively simple spreadsheet model, sediment loading from Citico Creek Watershed is being estimated and analyzed. A pathogen (bacteria) model following general accepted theoretical equations is being employed to estimate bacteria loading. Data collected and analyzed from Water Quality Program initiatives and programs are being used as model inputs, referenced with comparable literature and applications from EPA, TVA, and Virginia Tech. Sediment modeling is being conducted by load and bacteria modeling output is concentration – following TMDL guidelines.

Analyses using surface models may be performed relatively inexpensively to quickly identify critical areas within watersheds or stream reaches that are known or suspected to have major pollutant sources or related water quality problems. Such models are also useful in providing preliminary estimates of the effect of pollutant loading, and the subsequent effect of pollutant load removal, on water quality condition. The present initiative will, among other outcomes, serve as tools for watershed planning, resource allocation, and water quality management purposes.

1.4 Purpose and Scope of Document

This Watershed Characterization and Simulation Report will build upon a previously published Preliminary Watershed Characterization Report developed by the City of Chattanooga Stormwater Management Division. This 2005 document identifies and describes in detail the social characteristics of Citico Creek Watershed. The Report also introduces past, present and future mitigation, monitoring and outreach programs for the planning area. The present document will build upon that, and other relevant planning documents, to identify physical watershed characteristics such as specific data on physiographic and soils, land use/land cover, known or suspect point sources of pollutant discharge, and water quantity and quality to establish and foster a hydrologic and/or pollutant loading model(s).

The time and funds available for this watershed characterization and simulation limit the detail with which available data may be collated and analyzed. Consequently, certain assumptions have been made concerning the reliability and accuracy of the to-date data collection and processing. In particular, it is assumed that past water quality samples were handled and processed in accordance with state and federally accepted protocols. The raw data was not examined for errors in transcription, reporting, or censorship (i.e., values exceeding approved limits not reported). As a result of such limitations, the values depicted during this initial review should not be considered final or absolute, but still appropriate for planning purposes and model development. The goal is not only to continually improve the protection and restoration of the watershed, but also to improve the process.

Additionally, it is assumed that no local (state of Tennessee) standard for either a watershed characterization report or a simulation report have been established or published. As such, the present document identifies needs for long-term modeling in city jurisdictional watersheds, as well as approaches on how to best fit these needs. Additionally, this report presents the approach to be followed in constructing and calibrating such a pollutant loading simulation. The major steps in developing the model application consist of: 1) characterization and segmentation of the watershed (e.g. land use/land cover, impervious cover, and water quality data, (Section 2), 2) collection and collation of model input data (e.g. spatial, hydraulic, meteorologic, water quality parameters; Section 3), 3) conducting pollutant simulation work using the best available data at the time (Section 3) and 4) calibration and validation of the model (Section 3). Section 4 goes on to suggest how model output may then be applied to TMDL implementation strategies. Also included in this section are additional suggestions on how a comprehensive watershed management plan may be locally developed for Citico Creek Watershed.

This Watershed Characterization and Modeling Report is being prepared and distributed for review and comment by stakeholder agencies associated with Citico Creek Watershed, Tennessee River, City of Chattanooga, Hamilton County, and the state of Tennessee. The ultimate goal of this document is to establish the status and trends of the water resources of Citico Creek Watershed, identify impacts experienced, determine the likely causes or sources of those impacts, and describe and evaluate the watershed physical environment. This report should not however be an end point, but rather set the stage for a dynamic, comprehensive Watershed Management Plan. The purpose of a management plan is to further guide restoration, retrofit, and preservation efforts aimed at achieving specific water quality goals and conditions. It is anticipated that through the successful development and implementation of a site-specific management plan, the water resources of Citico Creek will be a safe, unimpaired, fully functioning and supporting stream ecosystem.

2.0 Watershed Characterization

Citico Creek Watershed is the only watershed that begins and ends inside Chattanooga city limits and associated jurisdictional boundaries. Citico Creek begins along the top of Missionary Ridge and meanders west through several neighborhoods (Bushtown, Churchville, Avondale, Orchard Knob, and East Chattanooga), commercial and industrial complexes, and a major rail yard prior to discharging into the Tennessee River. The planning area includes 12.49 linear miles of (USGS "blue line") stream draining 2,530 acres of watershed (Figure 1.2). To address spatial heterogeneity, Citico Creek Watershed has been divided into 23 sub-basins ranging in area from 10.5 to 369 acres. These 11-digit hydrologic units were derived from corresponding source streams or tributary (drainage) watersheds. These delineations are used in this planning document.

The following section will characterize the physical and aquatic conditions of Citico Creek Watershed, specifically detailing local physiography, land use / land cover, current watershed conditions, and past and current water quality conditions. The reader is referred to a previously published City of Chattanooga document for a thorough watershed characterization report detailing social conditions of the planning area, specifically providing estimates on demographics, housing density, and other social statistics. The Citico Creek Watershed Plan and Preliminary Characterization Report may be accessed via the internet at:

http://www.chattanooga.gov/Files/NPDES-CiticoWATERSHEDPLAN.doc.

2.1 Physiography and Soils

The Ridge-and-Valley ecoregion, also referred to as Level III Ecoregion 67, is a lowland region between the Appalachian mountain chain to the east and the Cumberland Plateau to the west (Figure 2.1). As a result of extreme geologic folding and faulting events, the region's roughly parallel ridges and valleys have a variety of widths, heights, and geologic materials, including limestone, dolomite, shale, siltstone, sandstone, chert, mudstone, and marble. Springs and caves are relatively numerous. Valley floor streams have moderate to low gradients with bedrock, gravel, and sandy substrates. Streams of limestone-origin are generally well buffered and slightly alkaline.

Within the ridge-and-valley region, Citico Creek Watershed lies within the Southern Limestone/Dolomite Valleys and Low Rolling Hills (sub-Ecoregion 67f), which forms a heterogeneous region composed predominantly of limestone and cherty dolomite. Landforms are mostly low rolling ridges and valleys, with few steep ridges. As a result of the ridge-and-valley topography, sections of the watershed contain sensitive areas in the form of steep slopes and flood zones. In most areas, the difference in elevation between the valleys and the adjacent ridges is between 80 and 150 feet (Figure 2.1). Bedrock geology consists of Quaternary cherty clay solution residuum and Ordovician dolomite and limestone. Soils vary in their productivity under the soil series Colbert, Dewey, Fullerton, Sequatchie, and Talbott (Figure 2.2, USDA 1982). All of these soils are moderately- to well-drained with moderate to high permeability. Table 2.1 below defines and describes soil series present in the planning area.

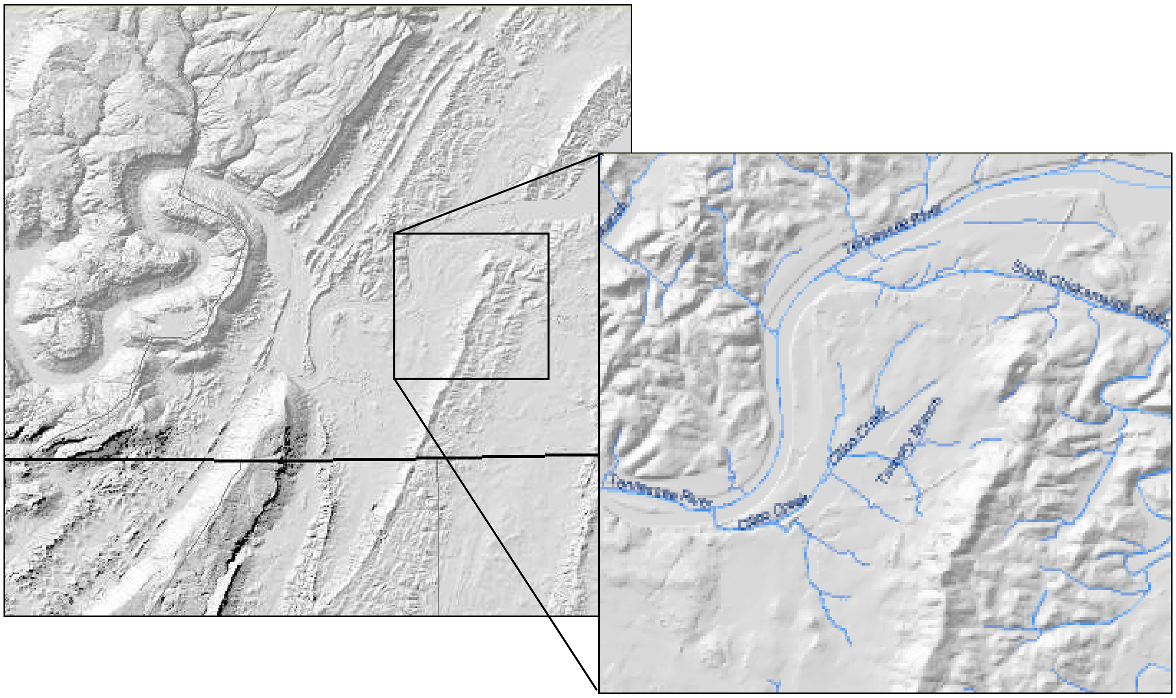

Figure 2.1. Physiographic map of Citico Creek Watershed. Maps extracted from USGS, National Elevation Dataset (NED), map scale on left is 1:308,104, right is 1:56,000.

Figure 2.2. Soil Series map of Citico Creek Watershed outlined in blue. Note mostly three major soil series present: CdC Colbert-Urban, FuE Fullerton cherty silt loam, and SfB Sequatchie-Urban; Refer to USDA 1982 for additional soil series descriptions.

Table 2.1. Soil series classification and description within Citico Creek Watershed; adapted from USDA 1982.

Soil Series		Area within Watershed (ac)	Landscape position	Percent Slope	Drainage Class	Depth	Permeability	Taxonomic Class
Tad	Talbott silt-loam	23	Moderately steep soil on limestone uplands	12 - 25	Well-drained	36 in	Moderately slow	Fine, mixed, thermic Typic Hapludalfs
DeB	Dewey silt-loam	13	Uplands in limestone valleys	2 - 6	Well-drained	> 60 in	Moderate; High available water capacity	Clayey, mixed, thermic Ultic Hapludalfs
DeD	Dewey silt-loam	25	Uplands in limestone valleys	12 - 25	Well-drained	> 60 in	Moderate; High available water capacity	Clayey, mixed, thermic Ultic Hapludalfs
FuD	Fullerton cherty silt-loam	39	Side slopes of ridges, underlain by limestone	12 - 25	Well-drained	> 60 in	Moderate; Moderate to High available water capacity	Clayey, kaolinitic, thermic, Typic Paleudults
FuE	Fullerton cherty silt-loam	359	Side slopes of ridges, underlain by limestone	25 - 40	Well-drained	> 60 in	Moderate; Moderate available water capacity	Clayey, kaolinitic, thermic, Typic Paleudults
FwD	Fullerton - Urban Land Complex	40	Gently sloping, urban	3 - 40	Well-drained	> 60 in	Deep, moderate; High available water capacity	Clayey, kaolinitic, thermic, Typic Paleudults
SfB	Sequatchie - Urban Land Complex	427	Gently sloping, urban	2 - 7	Well-drained	46 - 61 in	Moderate; High available water capacity	Fine-loamy, siliceous, thermic Humic Hapludults
CdC	Colbert - Urban Land Complex	1604	Gently sloping, urban	2 - 12	Moderately well-drained	40 - 60 in	Very slow; Moderate available water capacity	Very-fine, montomorillonitic, thermic Vertic Hapludalfs

Watershed-specific data on annual precipitation is not readily available or published, although a National Climatic Data Center approved weather station is situated 3.5 miles to the east of the planning area, at the Chattanooga Metropolitan Airport – Lovell Field. Documented data from this stationary gauge will serve as adequate for Citico Creek Watershed due to such close proximity. Annual precipitation for the watershed averages 54.52 inches (30-yr average), although year-to-year precipitation volumes and patterns may vary (Figure 2.3). Generally, when considering the 30-yr average, the winter months produce the greatest volume of precipitation locally. Recently however (5-yr average), convectional rain storms in July have produced substantial rainfall events and volumes. Average summer temperatures range from 69 to 89 ºF, and January temperatures range from 28 to 47 ºF.

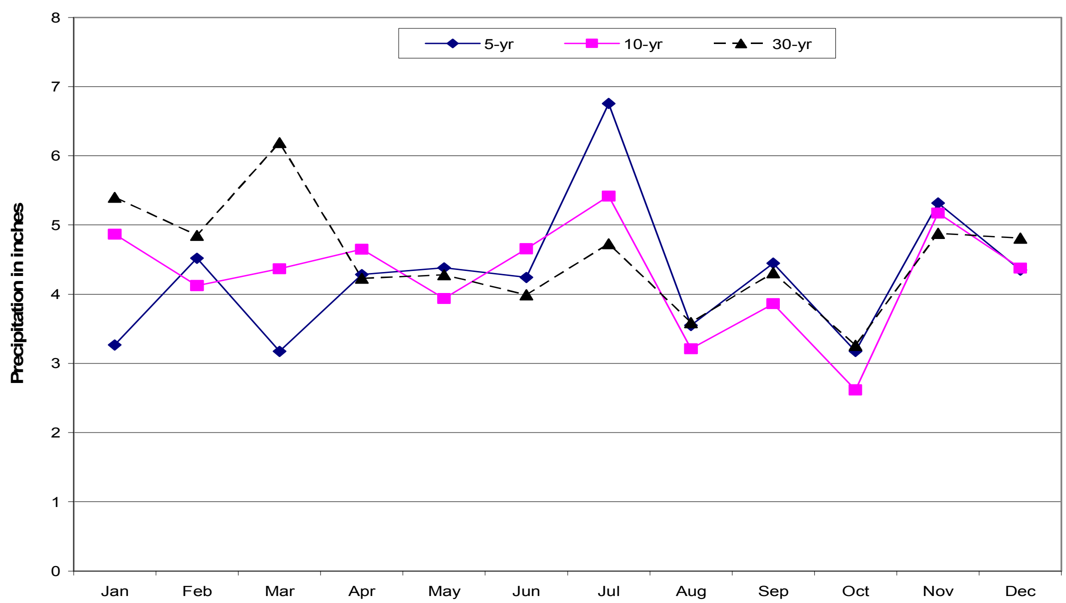

Figure 2.3. Annual precipitation patterns for Citico Creek Watershed noting 5-, 10-, and 30-year averages. Data from National Climatic Data Center, NOAA, Asheville, NC.

2.2 Land Use

Landscape and stream properties within a watershed reflect not only the physical and geologic context of the land, but also those associated with anthropogenic values and priorities. Such ideas are often reflected in the mix of land uses in an area, and in the diverse activities associated with a land use. Land use information is important in many applications, i.e. tax assessment, urban planning and environmental management. For diffuse source pollution management, complete and accurate land use classification is essential because the pollutant concentrations and runoff rates are correlated to land use more so than land cover.

Citico Creek Watershed is highly urbanized, with pockets of dense forest and small fields. White oak forests, bottomland oak forests, and sycamore-ash-elm riparian forests are the common community types, which make up small fragmented segments of woodlands scattered within urban areas. Additional dense forest communities are located along the northeastern portions of the planning area, abutting Crest Road and Missionary Ridge, where this often steep topography blocks rapid or dense developments.

The foundation of the land use analysis was based on color aerial photography taken in February 2006, with flight plan parameters determined by analysis of project requirements. The challenge of inferring land use classifications from spectral signatures of aerial photography certainly depends on resolution and information from ancillary data. Picture resolution used for the current analysis was 6-inches, or 7000 x 4000 pixels for a 3500 x 2000 foot quadrant. These values are well above any USGS land use / land cover dataset, resulting in accurate capture of the fine, respective spectral signatures associated with the various land uses and cover types.

These photographic data were digitized into a GIS database that consists of information on watershed features such as streambank and roadways, open fields and forests, and any operations that are known or suspected to be sources of pollution. The desktop GIS uses ArcView software (ESRI, Redlands, CA) for managing and viewing the data generated by the land use analysis. This combination of tools allows the user to investigate relationships among various geographic and/or land use features. This methodology also serves as a working verification as each image layer is related and must coincide with others.

A significant component of such a land use inventory is accurate knowledge of the natural and cultural characteristics of the study area. This knowledge can be used to confirm, or in some cases override, the aerial photography and GIS model, especially as land uses change with time. Whenever possible, the photographic interpretations offered for the study area were referenced and updated with site visits and consultation with city, county, and state personnel throughout the characterization process. These visits also provided observations of the relationships of terrain, land use, and stream network. It is believed that incorporating such supporting ancillary data provide greater information on the relationships among variables and in generating more accurate land maps.

Utilizing the resources and tools above, the planning area was divided into unique polygons based on land use characteristics, as interpreted from aerial photography and site visits. Each polygon was assigned a land use code following Anderson and others (1976) Level III Classification, and grouped into the major headings of Residential, Commercial, Industrial, Open Space, and Roads and Rights-of-Way (ROW). Results from the land-use analysis are presented here with greater detail and definition of each land-use class.

From this analysis, it is estimated that 39.3% of the watershed is made up of single-family homes, with an additional 16.7% of the watershed as multiple family units (e.g. apartments, duplexes). Industrial and institutional properties comprise 13.3% of the watershed land use and commercial properties make up 2.2%. Institutional sites here refer to government buildings, religious facilities, and health care facilities. Construction sites (defined herewithin as additions, demolitions, excavations, and/or grading activities) account for 1% of the watershed as of July 2007. Open space is estimated to comprise 14.1% of the watershed. Open space here refers to large vacant or undeveloped lots, city recreational facilities, cemeteries, and forests. The remaining 13.4% of the watershed is classified as ROW. Acreage values for each land class are further defined in Figure 2.4 below.

The Chattanooga-Hamilton Regional Planning Agency (RPA) has developed neighborhood-specific land use plans serving as guides for future growth and development in a manner that will help improve the long-term livability of the respective community. As the watershed contains many neighborhoods and communities (Avondale, Bushtown, Glenwood, and Orchard Knob), all the respective Neighborhood Plans must be referenced and used for future land use guidance (RPA 2000, RPA 2002, RPA 2004).

After referencing the neighborhood plans of the respective communities within the planning area, the watershed is generally comprised of eight basic zones:

- R-1 Single Family Residential
- R-2 Light-Density Residential Mix
- R-3 Medium-Density Residential Mix
- R-4 High-Density Residential Mix
- M-1 Manufacturing
- M-2 Light Industrial
- C-2 Convenience Commercial
- O-1 Office / Residential

As seen in Figure 2.5 below, much of the area west of the railroad is zoned for Manufacturing, and much of the area to the east is designated for Single Family Residential. Over the past several decades, there have been a number of zoning changes within the planning area boundary. The classifications are meant to be broad enough to provide flexibility in the implementation of the neighborhood plan while at the same time offering clear direction in making informed zoning decisions. For additional information on the current development trends and zoning within the planning area, the reader is referred to the documents by the RPA documents mentioned above.

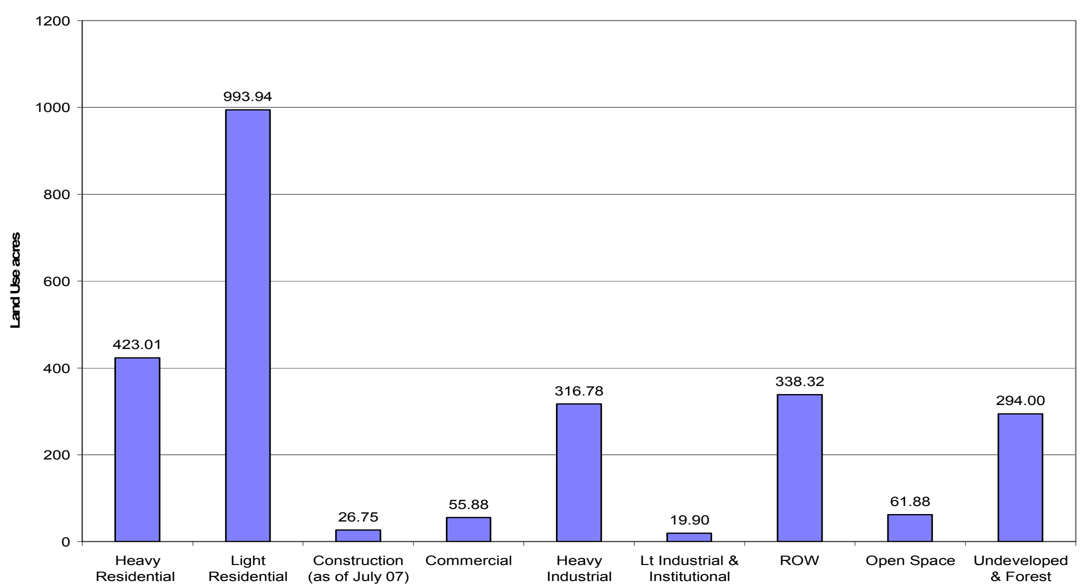

Figure 2.4. Major land use distribution (in acres) within Citico Creek watershed.

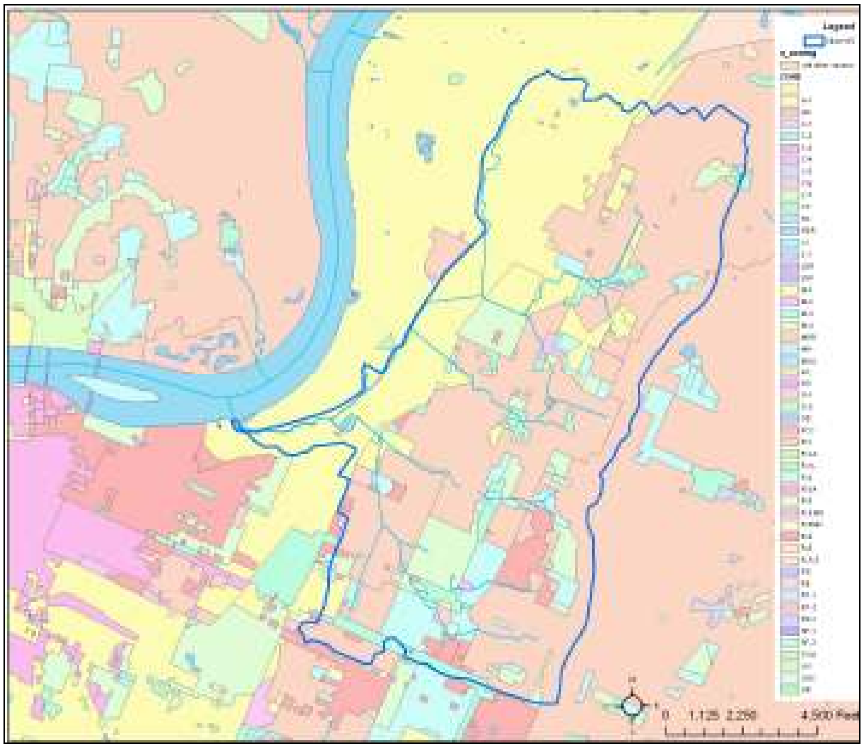

Figure 2.5. Zoning ordinances for the Citico Creek Watershed, outlined in blue. Refer to Chattanooga-Hamilton County RPA documents for additional code definitions.

To support this urban setting, a great deal of urban underground stormwater and sanitary sewer infrastructure has been put in place. The practicalities of urban stormwater management often require stormwater quantity management issues of flood protection, public safety and drainage economics to be addressed (often at the expense of stormwater quality). Out of sight and out of mind, conventional storm drainage systems have been viewed as an essential component of urban infrastructure and a necessary precondition for development. These systems have been designed to support a single function: to convey storm runoff away from developed areas as quickly as possible, minimizing the risk of flooding and property damage.

An infrastructure inventory program (locally referred to as the As-Found project) has been contracted by the City of Chattanooga which has provided an accurate location of each structure that can be used to model the system in GIS. This inventory for Citico Creek was completed Spring 2007, with 6,019 structures identified and inventoried. Included in the inventory are 4.2 miles of pipe of various substrates (corrugated metal, reinforced concrete, high-density polyethylene, PVC, asbestos cement), 9.2 miles of open, earthen channel, and 4.7 miles of rock-and-mortar or concrete lined channel. . Locations of the various stormwater structures are displayed in Figure 2.6.

Figure 2.6. Location and description of the various stormwater structures identified and inventoried via the City of Chattanooga funded As-Found project.

Included in this inventory is a recently converted 3,000 ft section of rock-and-mortar channel in to a natural earthen channel located by Carver Recreational Facility. Sections of Citico Creek were hydromodified by the Works Progress Administration (WPA) during the 1930's and 40's via channelizing the stream and lining it with concrete or rock-and-mortar. The stream restoration project was facilitated by the City of Chattanooga, TDEC, the Army Corps of Engineers, the Tennessee Valley Authority, Chattanooga Metropolitan Airport and Parkridge Medical Facility.

As with stormwater infrastructure, the sanitary sewer infrastructure of Citico Creek Watershed is an essential, although often overlooked and underappreciated, municipal utility. Though this infrastructure generally has a single purpose, the conveyance of domestic, commercial and industrial wastewater is one of great importance for human health, environmental impacts and general quality of life. Deteriorated or damaged sewer lines have the potential to leak raw sewage into the ground which can pollute surface water with pathogens, creating a potential health hazard. Additionally, compromised sewers can provide a portal for groundwater and rain to enter the main sanitary sewer system, causing the system to become overloaded and therefore resulting in overflows and increased treatment costs. It is therefore critical that municipal public works departments maintain a reliable and structurally sound sanitary sewer condition.

For earlier analyses and reports, City of Chattanooga staff have evaluated the date at which the sanitary infrastructure was installed within Citico Creek Watershed. Installation dates range from 1907 to 1973, which is not uncommon in many jurisdictions. However, this advanced age often results in compromised structural, operational, and performance deficiencies, leading to possible sanitary discharges increases due to cracks in the system. This problem is particularly harmful in the planning area as many sewer lines run perpendicular or often parallel to Citico Creek, various tributaries, or associated storm drainageways, as seen in Figure 2.7. Many sanitary pipes are visible under road culverts that drain the watershed. These occurrences then have the potential to discharge when the structural condition is jeopardized.

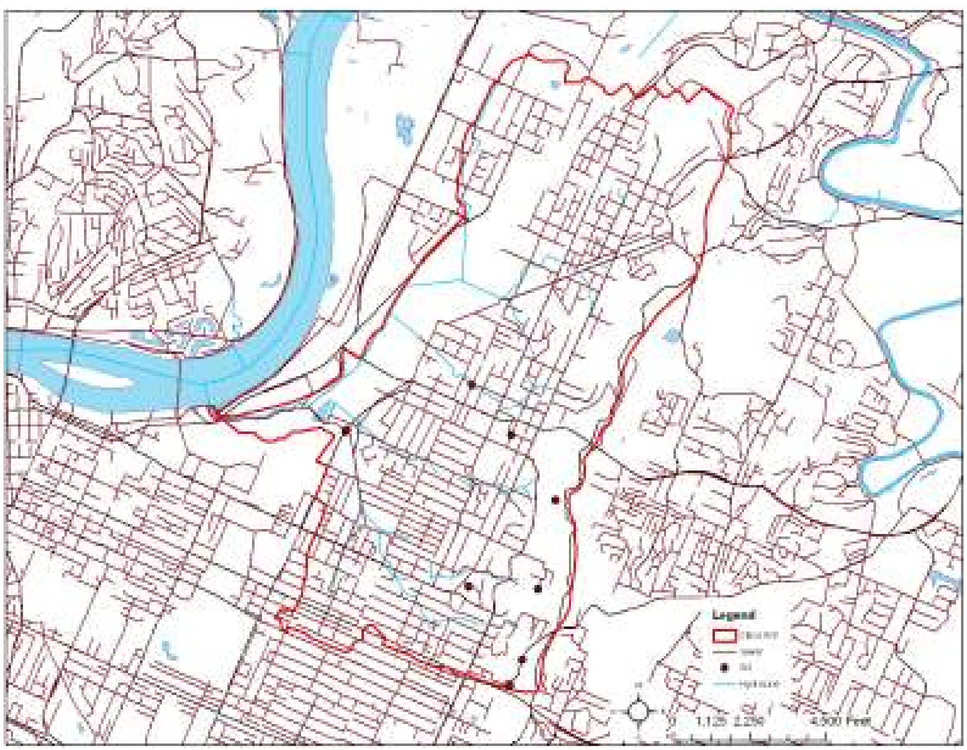

Figure 2.7. Schematic of sanitary sewer lines within Citico Creek Watershed (red lines), sanitary sewer overflows (red dots), and proximity of each to the creek (blue lines).

An additional concern of sanitary sewer lines within Citico is the presence of sanitary sewer overflows, or SSOs, resulting in untreated or partially treated sewage releases from the sewer network. Such overflows may be related to content of wastewater surpassing line capacity, or blockages in the system during both wet and dry weather. SSOs have a variety of causes, including severe weather (high volume or intensity of rain), line breaks, line blockages, power failures, operational errors, inadequate sewer capacity or design, and vandalism. Such discharges may result in overflows reaching city streets, sidewalks, and other overland outlets. Due to the resulting public health and environmental concerns, EPA prohibits municipal SSOs unless authorized by a NPDES permit.

Since February 2006, nine sanitary sewer overflows have been observed and reported within Citico Creek Watershed. All of these occurrences have been reported in the southern section of the planning area where a high density of sanitary infrastructure exists (Figure 2.7). These overflows stem from various causes as seen in Table 2.2, and lead to compromised surface and subsurface water quality. The wastewater in such SSOs have the potential to further impact designated uses of local waterways and jeopardize any structures and land sues in the overflow path. To contain such hazards, all observed SSOs are contained and corrected by City of Chattanooga personnel within hours of being reported. Additionally, any site that is known or is suspected to repeatedly overflow is monitored for several weeks following any reporting.

Table 2.2. Sanitary Sewer Overflows observed in Citico Creek Watershed since February 2006.

Address	Source	Destination	Vol (gal)	Cause(s)	Correction
Birds Mill & Shallowford	Manhole	Land, Storm Ditch	3,700	Trash/Grease	Cleaned Line
Mission Ave & Crest Rd	Mainline	Citico Creek	500	Pipe Defect	Repaired Line
519 Fisher Avenue	Mainline	Land	50	Blockage/trash, roots, grease	Cleaned MH, cut roots
808 N. Holtzclaw	PumpStat	Stream	1,000	Power Failure	Restored Power
808 N. Holtzclaw	PumpStat	Ditch	54,000	Power Failure	Reset Pump
2406 Shady Ln	Service Line	Ditch	100	Blockage/trash, grease	Cleaned Line
1315 Arlington Ave.	Manhole	Land, Storm Ditch	6,200	Blockage/trash, roots	Cleaned MH, cut roots
7 Shallowford Rd	Service Line	Land, Storm Ditch	800	Blockage/trash, roots	Cleaned MH & mainline
1910 Roanoke Ave	Mainline	WPA Ditch	200	Broken pipe	Temporary repair

Many customary urban structures, and their drainage basins, are located outside of the watershed and have no immediate impact on the watershed. Chattanooga Metropolitan Airport is positioned to the east of the planning area, along with large centralized shopping areas such as Hamilton Place Mall. Although the watershed does contain single, or clustered industrial sites, traditionally large industrial parks are to the north and east, outside of the planning area. Similarly, major thoroughfares such as Interstates 24 and 75 along with state highways are located to the east and south of the watershed.

From these land estimates, it is noted that 2,174 of 2,530 acres are considered urban. As a result of the highly urbanized landscape, much of the planning area contains impervious surfaces, such as roadways, parking lots, sidewalks, and buildings. Imperviousness represents the imprint of land development on the landscape, and as such is a useful indicator with which to measure the impacts of land development on aquatic systems. Additionally, imperviousness is one of the few variables that may be explicitly quantified, managed and controlled at each stage of land development. Such values have also consistently been used by the hydrologic community to model pollutant runoff and make infrences regarding stream water quality and quantity (Schueler 1994).

Such imperviousness changes the flow characteristics of streams within a watershed, including increased amounts of water the stream must carry during rain events (peak flows), increased flooding frequencies, and lower base flows. This often results in expedited channel alterations, increased sediment loads, and loss of aquatic and riparian habitat as soil and vegetation are scoured from the bottom and banks cave into the stream.

Employing the GIS database tools along with frequent site visits, percent imperviousness was estimated by tallying building footprint, paved parking areas, and road acreages for each basin within the planning area. Over the entire watershed, nearly 32% of the area, or 814 acres, is considered impervious; although individual values vary among each of the 23 sub-basins (Table 2.3). This value is classified as impacted or stressed after Schueler (1994a, b; Figure 2.8), and is thereby considered to be a major source of pollutant loading. This classification affects stream health by altering natural hydrology, habitat structure, water quality and biodiversity of aquatic systems. At this stage, proper stormwater management or low impact development (LID) practices can help mitigate any stream degradation.

The watershed contains nearly 60 linear miles of paved roads, primarily concentrating by and supporting nearby industrial, institutional, and residential areas. Width of roads varied throughout the area from 75 ft major roads to 25 ft residential corridors. It should be noted that roadways account for 42% of all impervious area in the watershed, while buildings (rooftops) account for 36%.

Table 2.3. Impervious surface estimation by sub-basin for Citico Creek Watershed. Road area was estimated as the product of road length and road width, which varyies between 25 and 70ft at each parcel.

Basin	Bldgs Area (ac)	Road Length (ft)	Total Road Area (ac)	Parking Area (ac)	Impervious Area (ac)	Basin Area (ac)	% Impervious
2	40.97	46103	45.86		86.83	369	23.6
101	0.49	2510	2.88	4.92	8.29	25	33.2
102.01	30.94	24015	26.30	25.83	83.07	161	51.6
102.02	13.39	16540	16.71	5.06	35.16	89	39.5
102.03	33.00	22260	24.94	38.84	96.78	229	42.3
102.04	4.28	5515	6.08	7.07	17.43	26	67.0
102.05	12.34	10680	11.93	7.00	31.27	102	30.7
103	8.53	8745	9.89	0.14	18.56	63	29.5
104	7.48	8805	10.11	4.22	21.81	54	40.4
105	12.08	19765	20.22	4.60	36.90	119	31.0
301	24.46	14635	16.80	22.40	63.66	221	28.8
401	9.76	23220	24.56	3.24	37.56	78	48.2
501	9.17	16030	17.29	3.87	30.33	113	26.8
502.01	10.42	10880	10.56	17.50	38.48	93	41.4
503	13.80	12680	15.00	4.78	33.58	81	41.5
504	10.53	14415	14.56	5.50	30.59	206	14.8
505	18.34	26150	28.19	6.18	52.71	231	22.8
601	1.76	2135	2.45	2.92	7.13	16	44.6
602	4.41	2255	2.78	1.03	8.22	17	48.4
603	3.15	1734	2.65	7.33	13.13	39	33.7
604	0.90	1840	1.44	2.62	4.96	11	45.1
605	12.69	16905	19.40	4.30	36.39	142	25.6
7	6.76	5594	7.33	6.94	21.03	45	46.7
Total	289.65	313,411	337.93	186.29	813.87	2,530	32.2

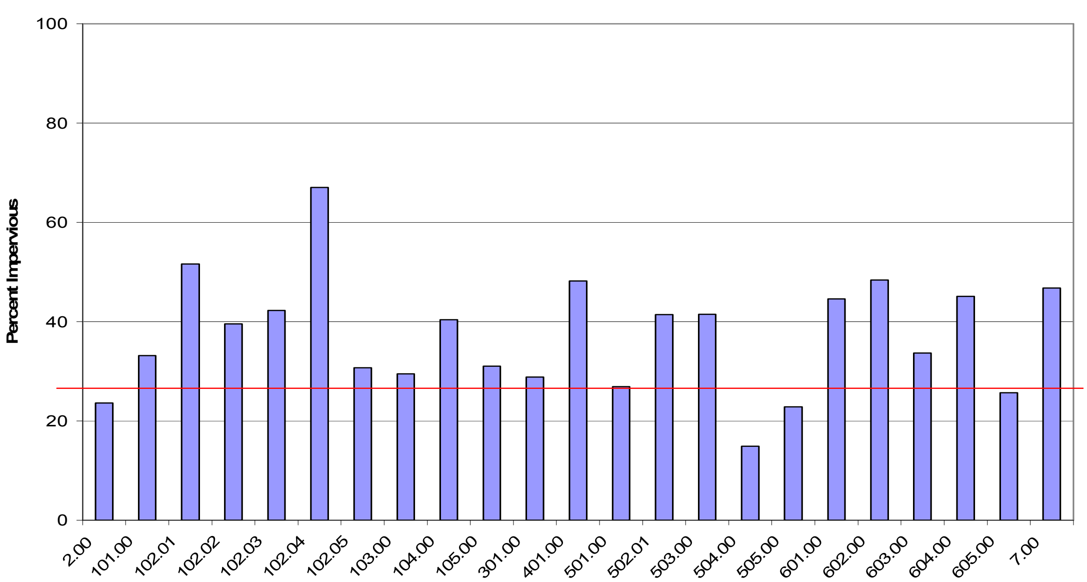

Figure 2.8. Estimates of impervious percentages of the basins within Citico Creek Watershed, with the solid line representing Schueler's (1994) threshold of impervious degradation at >25%.

For the purpose of this planning document, most pollutant sources within Citico Creek Watershed are classified as nonpoint sources, or diffuse sources which can not be identified as entering a waterbody through a single conveyance. The planning area does have however several designated point sources scattered throughout the watershed. The watershed contains a number of Multi-Sector General Permits for Industrial Activities (TMSP, Table 2.4), which monitors onsite stormwater management. No Ready-mix Concrete Facilities (RMCF) with NPDES permits reside in the planning area as of July 2007, nor is there a wastewater treatment facility (WWTF).

Table 2.4. List of Sites with Coverage under the Tennessee Storm Water Multi-Sector General Permits for Industrial Activities, as of March 2007. Data from TDEC.

Permit Number	Permittee	Location
TNR050688	Accu Cast Operations	1911 Crutchfield
TNR051014	Array Chattanooga	3600 N. Holtzclaw
TNR050599	Cannon Equipment	950 Riverside
TNR053700	Chattanooga Wilbert Vault	1322 Stuart
TNR051092	Lockwood's Auto Center	2317 Bragg St
TNR053888	Orange Grove Center	460 Dodson
TNR050413	Nu-Foam Products	1101 Wisdom
TNR056599	Parman Lubricants	1110 Stuart St
TNR051009	Roadtec, Inc.	2909 Riverside
TNR051336	Sphere One, Inc.	601 Cumberland Ave., Bldg. #32
TNR055069	TFS Fabricators, Inc.	806 N. Holtzclaw

Discharges from NPDES-regulated construction activities are considered point sources of sediment loading to surface waters and occur in response to storm events. However, since construction activities at a site are of a temporary, relatively short-term nature, the number of permitted sites and their environmental impacts at any given time or location varies considerably. Although most land in the watershed is already built out, or designated as open space, construction activities still occur.

Existing and future NPDES-regulated construction activities disturbing one acre or more are required to implement BMPs as specified in NPDES Permit No. TNR10-0000, General NPDES Permit for Stormwater Discharges Associated With Construction Activity. The permit requires the development and implementation of a site-specific Stormwater Pollution Prevention Plan (SWPPP) prior to the commencement of construction activities and must be prepared in accordance with good engineering practices and the Tennessee Erosion and Sediment Control Handbook. The SWPPP must also identify potential sources of pollution at a site that would affect the quality of stormwater discharges and describe practices to reduce pollutants in those discharges.

Since 1999, 321 permitted land disturbances have been documented in the planning area, and 24 are considered open or active as of January 2008 (Figure 2.9). These sites are the culmination of demolitions, fill sites, additions, and excavations. Major land disturbances presently occur in basins 02, and 102.03, both located in the southern portions of the area. Basin 02 contains the construction and additions to Orchard Knob

Elementary School, disturbing 6.5 acres of soil. Basin 102.03 contains grading and construction activities of facilities associated with Memorial or Parkridge Hospitals.

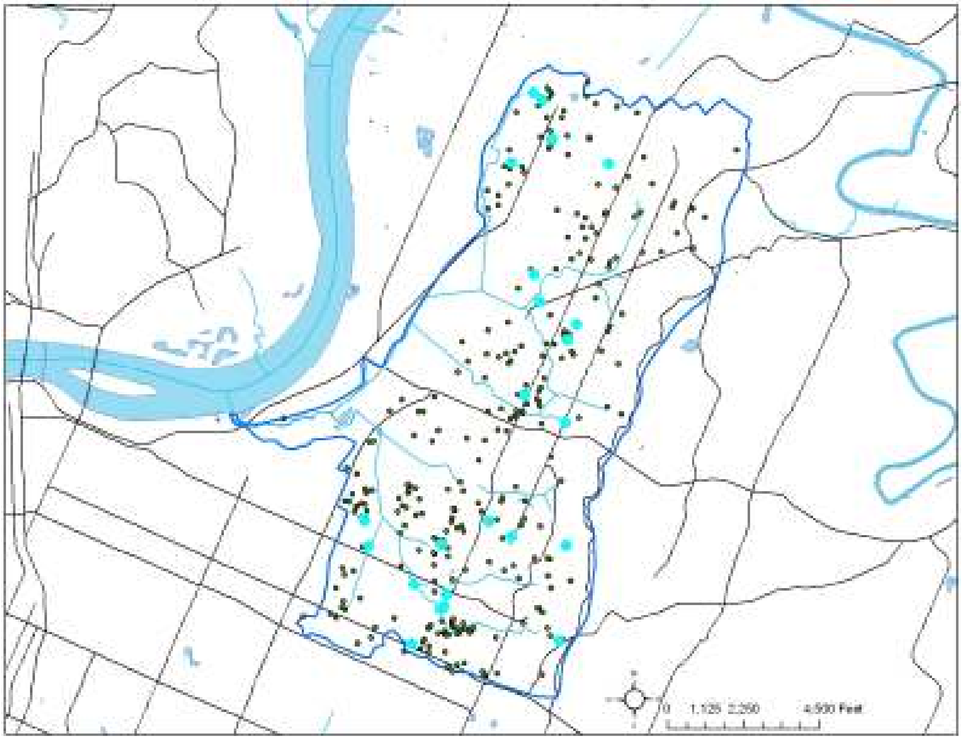

Figure 2.9. Location of permitted land disturbances in Citico Creek Watershed since 1999. Larger highlighted dots represent sites still active as of January 2008.

2.3 Watershed Condition

Proper management decisions, and ultimately corrections, stem from accurate identification, qualification, and/or quantification of the problem(s). Such evaluations of the various ecosystem functions of a watershed are necessary to help ensure adequate management and restoration decisions are being properly or effectively addressed. Similarly, such evaluations provide a baseline of the conditions of an area which may be used to chart progress in the future. Time and financial constraints often deter land managers and planners from establishing and implementing watershed assessment programs. However, it is important to recognize that such an investment may produce substantial gains later.

To provide sufficient information on the condition of Citico Creek Watershed, the City of Chattanooga has employed a dynamic myriad of research, monitoring, and assessment programs. Such an assessment of stream, stream buffer, land use, outfalls, and infrastructure permits a ranking of any stressors and further allows prioritizing of staffing, time and efforts. The procedures followed in such assessments were developed based on standard or accepted methods (e.g. EPA 2000, CWP 2004, Yetman 2001), modified as necessary to best fit local conditions and statewide requirements. Detailed field or desktop procedures and methods are not included in the present document, but it is worth noting that field measurement data and/or acceptable index samples or responses were characterized for water chemistry, physical habitat, land use and land cover, vegetation community metabolism, stream-side buffers, drainage and sanitary (sewer) infrastructure condition, and current pollutant evidence, among others.

2.3.1 Illicit Discharge Potential

As the MS4 often discharges directly to receiving waterbodies without treatment via stormwater drainage routes, it is particularly important that only stormwater is discharged and to ensure that illicit discharges are eliminated from the system. An illicit discharge here is defined as any non-permitted discharge to a regulated small MS4 or to the waters of the State that does not consist entirely of stormwater or allowable nonstormwater discharges. Depending on their source(s), illicit discharges may convey pollutants such as nutrients, pathogens, and metals to receiving waters. Such discharges are typically transitory or one-time events resulting from spills, breaks, dumping, or accidents. Continuous illicit discharges however may be identified, which are typically the result of a direct connection from a sanitary sewer, overflow from a malfunctioning septic system, or inflow from a nearby subsurface sanitary sewer that is malfunctioning.

To determine the potential severity for illicit discharges and further identify which subbasins or generating land use merit priority investigation, a desktop assessment of illicit discharge potential (IDP) was initiated for Citico Creek Watershed. Utilizing best available data on land uses, drainage areas, and a variety of screening factors suggested by the Center for Watershed Protection (CWP 2004), the individual basins of the planning area were screened and ranked for potential illicit discharges. Screening factors utilized locally for this desktop assessment include 1) past discharge complaints, 2) dry-weather water quality parameters (exceeding state appointed standards), 3) level of impervious cover, 4) age of development, and 5) number of sanitary sewer overflows.

Based on these quantifiable data, three basins scored or ranked as having a high potential for illicit discharges: basins 02, 105, and 102.01, all located in the southern portions of the watershed. Though much of the individual sub-basin characteristics are similar, these three basins ranked high due to past discharge detection and poor water quality monitoring results. Additional procedures and results may be reviewed in the Citico Creek Watershed Plan and Preliminary Characterization Report referenced above. Results from subsequent water quality monitoring and field assessments support the initial desktop assessment of these select basins having suspect water quality conditions.

As a result of preliminary data and analyses, the City initiated a Supplemental Environmental Project (SEP) or later known as Sewer Lateral Assessment Program (SLAP) designed as a proactive approach to identify and eliminate possible sources of illicit discharges. Since 2005, Water Quality personnel along with Moccasin Bend WWTF staff have implemented an aggressive smoke testing program to identify broken main sanitary sewer lines and broken sanitary service laterals. City of Chattanooga Department of Public Works repairs the main lines and works with property owners to repair the service laterals. Laterals are the portion of sewer network that connect individual properties to the public sewer network, and these lines are often in poor, defective condition possibly leading to subsurface infiltration and transport. According to Chattanooga City Code Section 31-4, it is the responsibility of property owner or user of the sewer to repair and maintain sanitary sewer service lines.

The goals of this city-wide program are to identify sources and eliminate discharges from the domestic sanitary sewage into the MS4 and to subsequently reduce stormwater inflow and infiltration into the Interceptor Sewer System. This project has been implemented by: 1) conducting smoke tests in target neighborhoods to identify the sources, 2) correcting (repairing or replacing) defective private service lines/laterals, and 3) removing illicit connections from residential properties to eliminate further discharges and reduce infiltration.

The sewer lateral may consist of cast iron, clay, PVC, or any combination of those and extends from the interior of/under the house to (usually) the center line of the street. Beginning June 2005 and ending May 2007, City of Chattanooga personnel have detected 945 anomalies, or broken structures associated with the sanitary service lines within Citico Creek Watershed. Examples of such anomalies include smoke stemming from cleanout caps, retention walls, or sidewalks, among others, from private residential or commercial lots. Detailed results specific for Citico Creek Watershed from this program are presented in Table 2.5 below. From these data, it may be noted that 74% of found infrastructure failures have been repaired (as of March 2008), and 78% of individual lots have been repaired.

Certain sections of the planning area displayed higher densities of failing sewer infrastructure than others as found through the SLAP or smoke testing program, perhaps due to age of sewer, age of neighborhood, pipe dimensions and capacity, or land use. Higher densities of anomalies were concentrated in the southern sections of the planning area, especially in basins 02, 102.02, 102.01, 102.05, and 401 (Figure 2.10). Some of these basins were identified as having a high discharge potential through the *a priori* Illicit Discharge Potential desktop analysis, thereby confirming and supporting this process.

Table 2.5. Results of the City of Chattanooga Sewer Lateral Assessment Program for Citico Creek Watershed. Data are from smoke tests dated June 06 to May 07 and repairs up to March 08.

Anomaly Type	Total Found	Repaired
Cleanout	355	278
Ground	490	344
Foundation	28	23
Sidewalk	14	12
Gutters	4	4
Utilities	8	0
Catch-basin	13	11
Other	10	13
Drainageway	4	2
Retaining Wall	6	2
Manhole	13	14
Total Anomalies	945	703
Total Properties	777	606

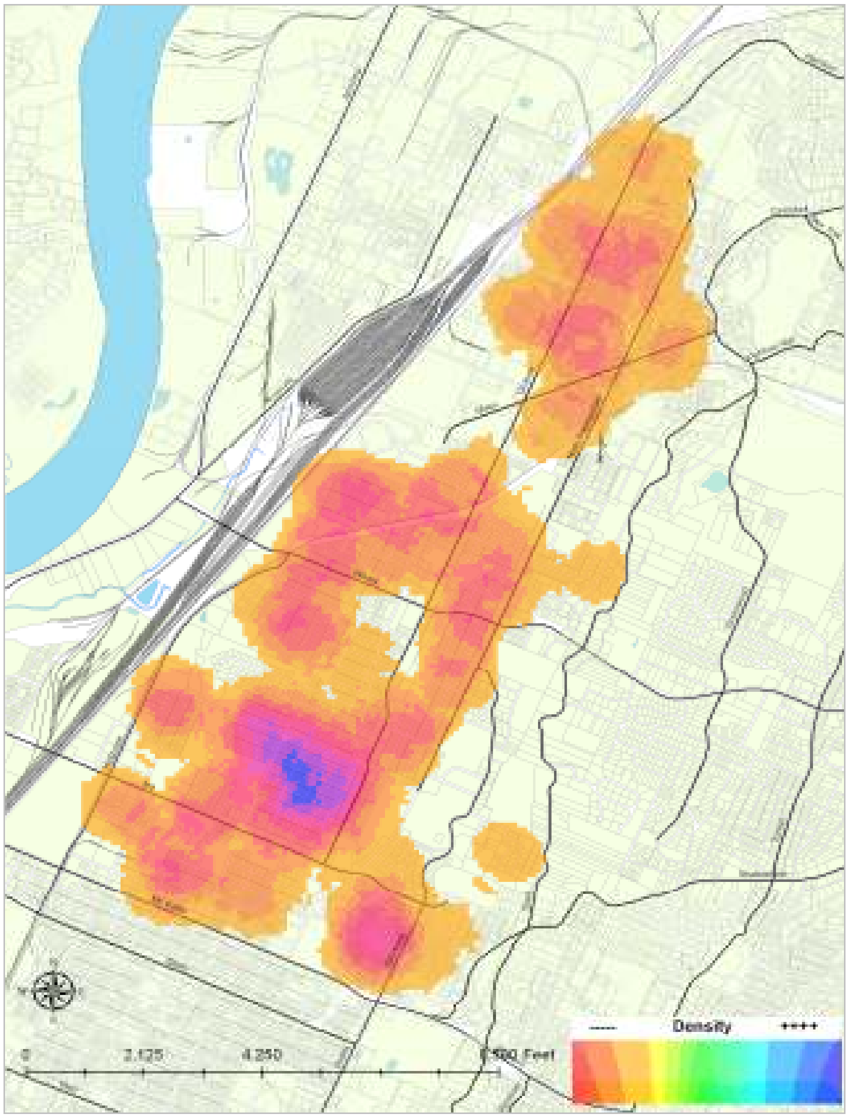

Figure 2.10. Density map of failing private sanitary lines within Citico Creek Watershed. Analysis stems from field data collected during smoke test events June 2005 thru May 2007.

2.3.2 Illicit Discharge Detection and Elimination

Beyond such significantly deleterious and continuous discharges identified above, the City of Chattanooga is committed to also finding intermittent, transient illicit discharges within the jurisdiction. To support this, the city is conducting rapid field screening to identify & track suspected outfalls & stream segments to detect illicit discharges in the storm drainage system. Through the City of Chattanooga MS4 NPDES permit, water quality staff have been employing an illicit discharge detection and elimination (IDDE) program composing of the following methods (similar to the documented Center for Watershed Protection's Outfall Reconnaissance Inventory [CWP 2004]):

1. Prioritizing areas using such resources as zoning maps, locations of previous illicit discharges, age of infrastructure, density and rate of development, and past or current water quality information.

2. Mapping the storm drainage system and referencing in a GIS format. Field data will be incorporated with GIS data and revised as necessary.

3. Detecting illicit discharges via dry weather discharge inspections of outfalls, opportunistic inspections such as non-stormwater city staff observing and logging discharge information, and through citizen call-in hotlines (311).

4. Tracing illicit discharges via inspections such as dye testing, optical brightener monitoring traps, electronic location of subsurface pipes, pipe televising, or smoke testing.

5. Establishing an appropriate, effective, and consistent enforcement program to ensure repair and prevention.

Field activities include the use of qualitative and quantitative tracers used to confirm the presence of suspected inappropriate discharges. Examples of these are shown in Table 2.6, with emphasis placed on quick and simple tests that do not require extensive time-consuming training and/or analysis. A total of 41 field screening sites have been identified and characterized within the watershed as outfalls or outfall structures draining greater than 50-acres (Figure 2.11). These sites are inspected on a 5-yr cycle to detect any illicit discharges or suspect intermittent flow.

As many public works crews conduct their regular duties in and around the storm drain system, crews are instructed to informally “keep a look out” for illicit discharges and conduct and document opportunistic inspections. If an employee observes evidence of an illicit discharge during an informal or non-routine inspection, he/she has been instructed to collect as much information about the potential illicit discharge as possible then contact the appropriate water quality personnel for additional tracing or investigation.

Table 2.6. Tracer parameters used by City of Chattanooga staff to identify illicit discharges.

Physical	Conductivity, temperature, odor, color, outfall condition, deposits/stains, vegetation, pool quality, benthic quality, oil sheens, clarity, floatables
Chemical	Dissolved oxygen, acidity, phosphates, chlorine, detergents, phenols, copper, ammonia

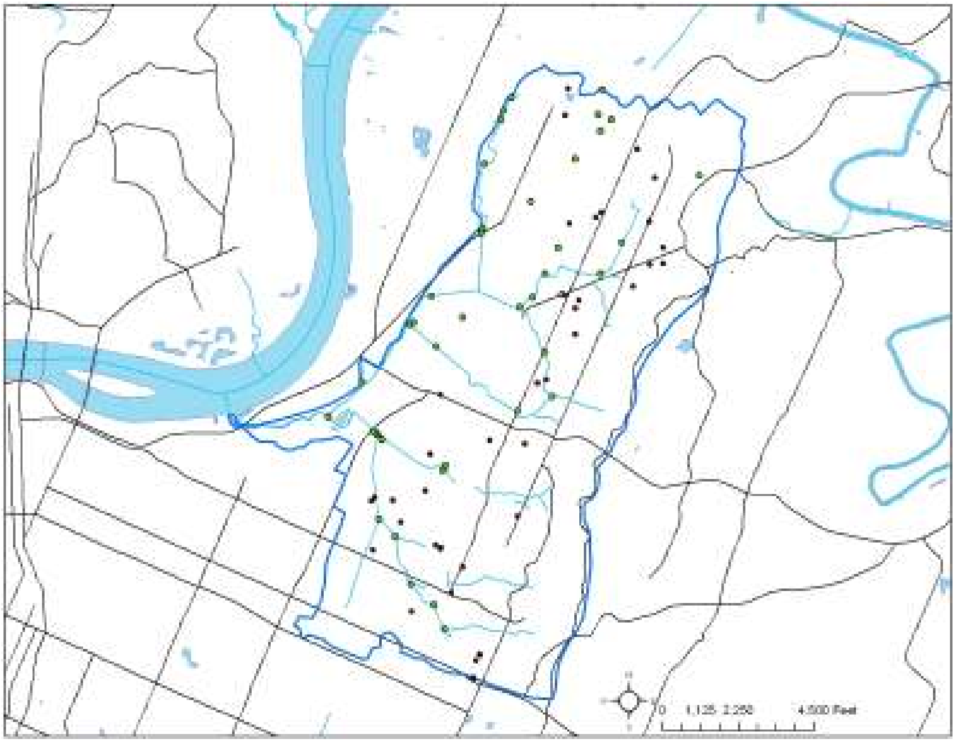

Figure 2.11. Locations of City of Chattanooga field screening sites (green circles), and detected illicit discharges (red circles) as part of the local IDDE program.

In accordance with ARTICLE VIII, CHAPTER 31, CHATTANOOGA CITY CODE, PART II, the City of Chattanooga has established the legal authority to control and prohibit illicit discharges. Article VIII, Division 6, Sec. 31-341(5) of the Chattanooga City Code prohibits the direct or indirect discharge into “Community Waters” or “Waters of the State” leaking sanitary sewers and connections, which shall have remained uncorrected for seven days or more. The purpose and objectives of establishing this authority by ordinance is to:

- control the contribution of illegal pollutants to the stormwater collection system
- prohibit illicit discharges to the stormwater collection system
- prohibit discharge of spills and disposal of materials other than stormwater to the stormwater collection system
- determine compliance and non-compliance
- require compliance and undertake enforcement measures in cases of non-compliance

Such authority allows Water Quality personnel to require immediate correction of any illicit discharges, with any failures to mediate said discharge resulting in issuance of civil penalty (usually a monetary fine) and/or citation to Court. It should be noted though that some illicit discharges stem from legal connections to the storm drain system. If such discharges are detected from a municipally approved connection, then stormwater officials may intervene and follow regulatory procedures to cease and desist such illicit discharges. Illegal connections to the storm drain system are almost automatically treated as illicit discharges, with the property owner (business or resident) held financially responsible for disconnection. For example, if an illicit discharge is a failing sanitary sewer line, the party responsible for the line must pay for the correction (see SLAP above).

Since October 2005, water quality staff have detected and eliminated 40 illicit discharges (Figure 2.11), varying from sewage, automotive fluids, and corn syrup. These discharges were identified via citizen complaints, field screening activities, routine and non-routine surveys, indicator monitoring, and visual stream inspections.

2.3.3 Visual Stream Inspections

Concurrent with field screening and illicit discharge detection and elimination programs, Water Quality personnel began a detailed and consistent stream inspection protocol to identify and evaluate pollutant inputs from compromised streambanks. Accurate evaluations of bank condition and erosion potential will help support management decisions and strategies. Conversely, this may help avoid implementing ineffective bank management strategies, overdesigning bank structures that generate unnecessary expenditures and impacts, and underdesigning structures that may ultimately fail. To meet these purposes, as well as to satisfy Tennessee TMDL and MS4 NPDES monitoring requirements, the City of Chattanooga has developed and implemented a Stream Corridor Evaluation Program (SCORE; City 2007) to survey all streambanks of Citico Creek Watershed.

The predominant processes of streambank erosion include: surface erosion, mass failure (sheet and planar), fluvial entrainment (particle detachment by flowing water), freeze-thaw cycles, bank collapse, positive water pressure, both saturated and unsaturated failures, and hydraulic and gravitational forces (Rosgen 1996, 2001). These processes have been and continue to be studied providing better understanding of the complexities involved. The individual and collective complexities and consequences of each physical process of erosion however preclude consistent and reliable streambank erosion indices or predictions. Additionally, the mechanisms controlling the rate of streambank erosion and sediment transport listed above are difficult to model with usable accuracy.

The assessment protocol developed and utilized by Water Quality staff provides a basic level of stream and streambank health evaluation based primarily on visual observations of each stream reach condition. Because of this relative simplicity, the methodology applied may be performed quickly; however it may not detect some resource problems caused by factors not located immediately beyond the area being evaluated. Overall, by examining the various physical and geologic parameters identified in Table 2.7, this program allows Water Quality staff to verify, inventory, and assess the length, substrate, condition and erosion potential of any and all stream or drainage channel at the sub-basin level.

Utilizing As-Found data and GIS data for the planning area, it was estimated that the area contains a total of 19.1 miles of direct drainage for the watershed (excluding road drains and associated pipes, insignificant grassed swales, assumed conveyances and spillways). Referencing Figure 2.5 above, much of the area does contain supporting drainage structures, but the streambank evaluation initiative concentrates primarily on natural stream channels. The SCORE program has identified that nearly 73% of the stream is open channel (Table 2.8), with the remaining classified as underground structural stormwater infrastructure facilitating rapid drainage. From these values, it is estimated that 25% of Citico Creek, as defined by the USGS hydroline, is currently concrete or rock-and-mortar, 48% is natural earthen channel, and the remaining 27% is closed (piped or culvert) channel.

Upon conclusion of the SCORE program in Citico Creek Watershed (from June thru December 2007) Water Quality staff evaluated nearly 60,000 linear feet (11.3 miles, or 81%) of the waterway. The remaining sections of the desktop inventory not physically evaluated were omitted due to lack of hydroline, physical obstructions such as active construction or landscape feature, inability to locate the channel, waterway being underground stormwater structure, or otherwise insignificance of the supposed waterway (e.g. six inch vegetated depressions).

Table 2.7. Physical and geologic parameters evaluated in the City of Chattanooga stream corridor evaluation (SCORE) program.

Site Conditions	Land use, blockages, stormwater (drainage) infrastructure, construction activities and severity
Water Conditions	(Presence of) flow, odor, algae, color, riffles, sheen
Bank Conditions	Bed material, soil type, channel dimension
Vegetative Conditions	Percent canopy, buffer width and density

Table 2.8. Estimated length of closed drainage and open channel for Citico Creek Watershed, as deciphered via GIS/As-Found data.

	Channel / Open			Closed			
	Earthen	Concrete	Total	Piped	Culvert	Total	Total
Total feet	48,514.5	24,980.3	73,581.3	22,112.8	5,379.8	27,492.6	101,073.9
Total miles	9.2	4.7	13.9	4.2	1.0	5.2	19.1

Analyses of stream evaluation data show no obvious trend of excellence or degradation of one basin over another; that is, no one basin appeared greater in condition over another within the watershed. Similarly, no one land use or land cover type exhibited better streambank condition over another. Overall rankings for the watershed ranged from 8 to 25 (out of a possible maximum severity of 35; Figure 2.12). In general, canopy cover for the watershed averaged 55%, which is expected as this is a highly urbanized area. Many stream corridor segments displayed vegetative canopy only immediately above the open channel with minimal extension beyond the bank. Average buffer width was roughly 20 feet on both right and left banks, with some segments displaying no vegetative buffer at all (Table 2.9). Channel dimensions varied throughout the planning area, with the general trend that natural channels were wide and deep, and concrete channels narrow and shallow.

One of the broader goals of this program was to quantify and rank erosion potential and overall streambank condition. This overall condition is designed to be a function of vegetative cover, blockages, infrastructure condition, proximity to construction, and erosion potential. Erosion potential for much of Citico Creek was found to be highly correlated with channel substrate more so than any other monitored variable listed. As seen in Table 2.10, earthen channels give way to greater erodability than concrete or concrete lined channels. This relationship was especially sensitive to percent clay content of the soil.

Total overall scoring was found to be correlated to vegetative condition more so than any other evaluated parameter. Overall streambank scores increased with a decrease in canopy cover (Corr coeff = -0.252, p=0.007). A weak, but significant relationship was also found with total corridor rank and bank substrate in that streambank segment scores increased with a decrease in cobble along the streambed (Corr coeff = -0.192, p=0.034). Cobble here refers to a rock fragment between 64 and 256 mm (2.5 to 10 in) in diameter, especially one that has been naturally rounded. From these analyses (Figure 2.13), it is suggested that increased canopy cover, buffer width, and cobble along the streambed improve overall stream corridor condition.

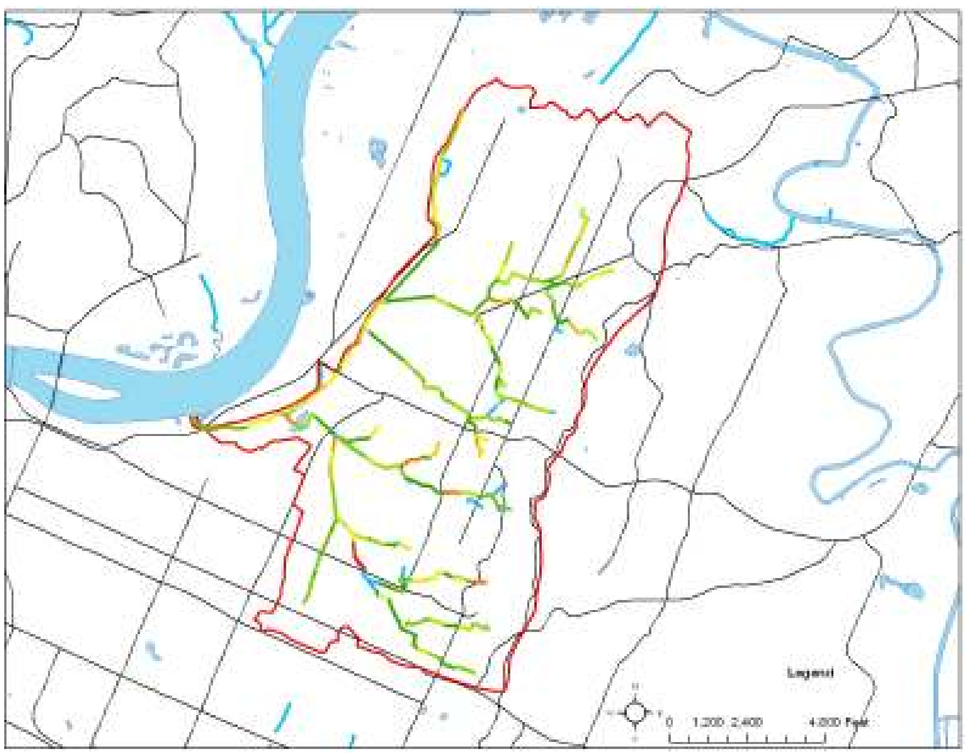

Figure 2.12. Results of City of Chattanooga SCORE analysis for Citico Creek Watershed. Colors represent ranking of severity where green to red represents minor to severe, respectively.

Table 2.9. Descriptive statistics from streambank corridor evaluations of Citico Creek Watershed. Data represent 123 segments (N) of 500 ft each collected June 2007 thru Dec 2007 spanning 59,771 linear ft; values are in inches.

	N	Minimum	Maximum	Mean	Std. Deviation
Canopy Cover (%)	113	0	100	55.06	22.007
Right Buffer Width (ft)	117	0	50	20.56	13.442
Left Buffer Width (ft)	117	0	50	19.22	13.588
Channel Top Width (in)	123	36	550	152.67	91.525
Channel Bottom Width (in)	123	18	260	83.07	54.697
Channel Depth (in)	123	10	220	47.03	29.523

Table 2.10. Correlation statistics of erosion potential of Citico Creek Watershed streambanks. Data represent 123 segments (N) of 500 ft each collected June 2007 thru Dec 2007.

	Substrate percentage	Cobble	Gravel	Sand	Silt	Clay	Concrete	Earthen
Erosion	Pearson Correlation	-0.038	-0.009	0.203	0.227	0.318	-0.302	0.302
	Sig. (2-tailed)	0.678	0.918	0.024	0.012	0.000	0.001	0.001
	N	123	123	123	123	123	123	123

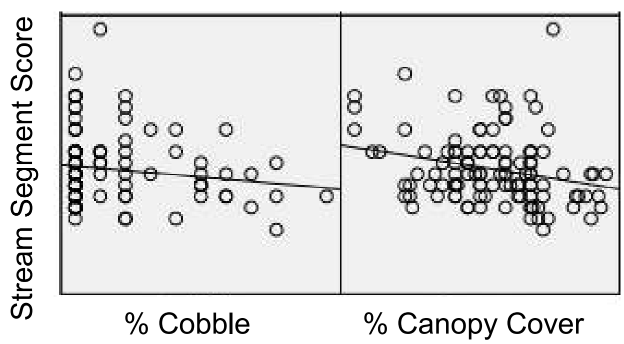

Figure 2.13. Scatterplot results for total stream segment score with percent cobble and canopy cover for Citico Creek. Data represent 123 segments (N) of 500 ft each collected June 2007 thru Dec 2007.

2.4 Water Quantity Assessment

The year-to-year variability in rainfall volumes and patterns has a significant influence on local water budgets and the overall hydrologic cycle of the watershed (see Figure 2.3 above). For example, 2007 was the driest year in the past ten years with only 38.6 inches of precipitation, and the past ten years have been noticeably drier than the 30-yr average of 54.5 inches. Intra-annual rainfall variability displays similar trends of not necessarily conforming to a set schedule, although summer and autumn months generally produce minimal precipitation for the region. Hydraulically, Citico Creek is subject to spring floods (Figure 2.14), but reduces to a near trickle during summer and autumn months, when the water quality here becomes critical.

Despite the massive structural manipulation of the stream corridor (as seen in Figure 2.6), drainage issues continue to be a concern for residents, engineers, and planners. Much of the creek itself has been converted into WPA concrete-lined ditches in an attempt to expedite flow away from residential areas. Unfortunately though, many consistent drainage issues remain. There are approximately 40 locations within Citico Creek Watershed that are prone to flooding primarily due to debris build-up (Figure 2.15). City crews routinely monitor these sites during rain events and remove blockages from pipes, culverts, and other stormwater structures. Part of the city-sponsored As-Found project is the identification and inventory of such structures, and their possible associated concerns. This effort has been, and will continue to be used to predict future drainage problems, evaluate opportunities to improve drainage basins and assist land development planners in establishing the optimum permanent stormwater BMPs.

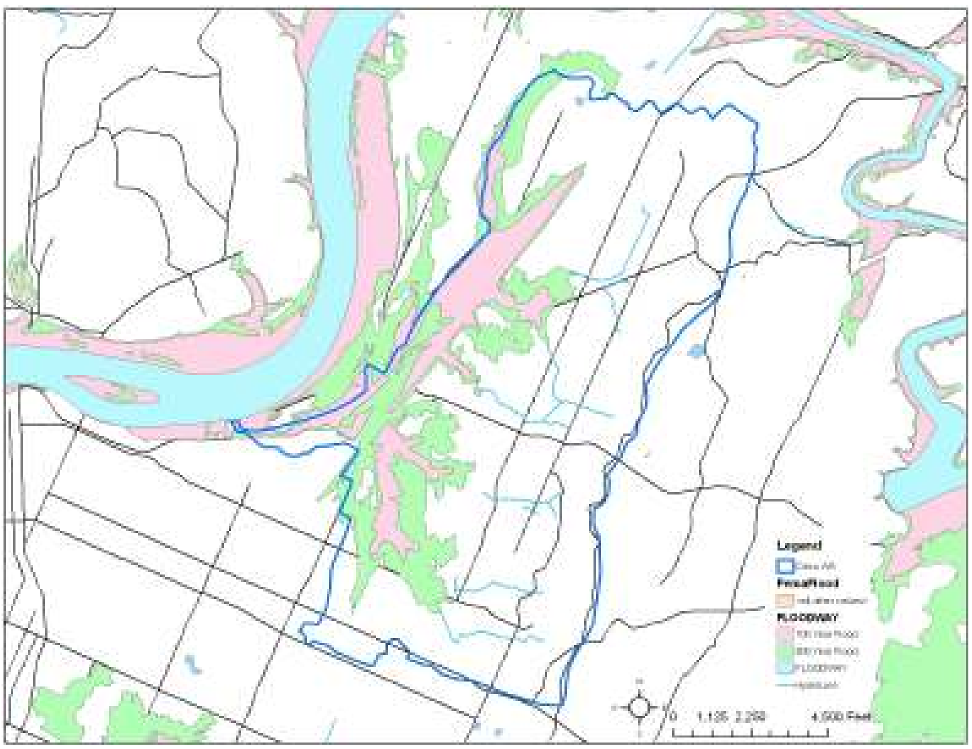

Figure 2.14. Citico Creek Watershed 100- and 500-yr flood zone, as defined by FEMA.

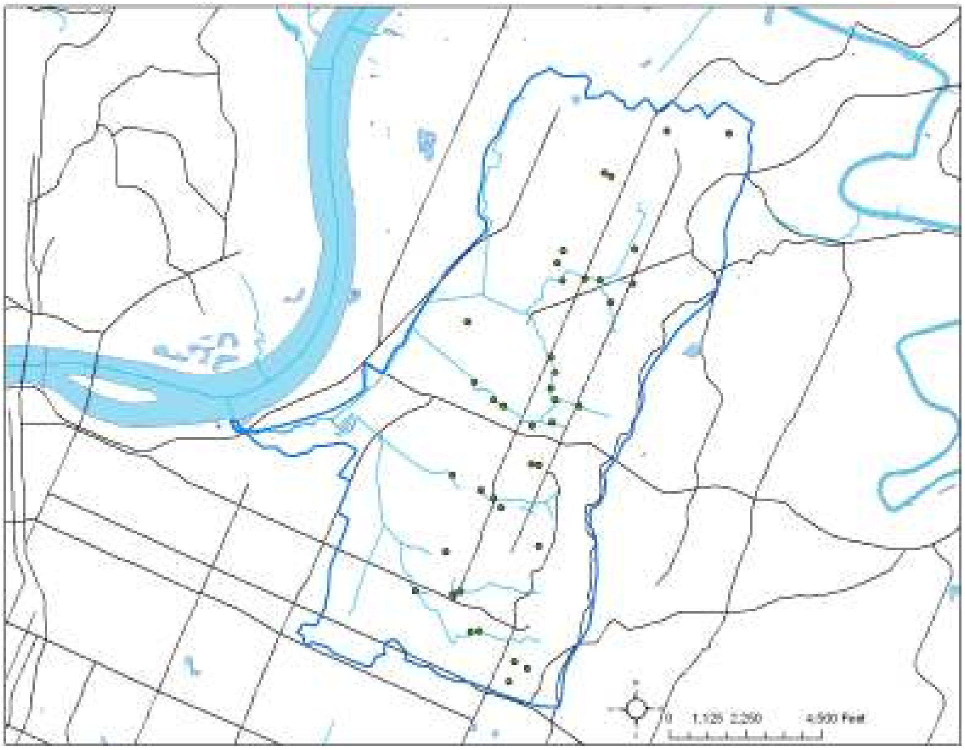

Figure 2.15. Location of continuous drainage sites of concern within Citico Creek Watershed.

Stormwater runoff, and ultimately downstream flow, is primarily (although certainly not solely) produced by infiltration-excess overland flow. That is, when rainfall intensity and volume exceed the infiltration capacity of the soil, the excess results in filled surface depressions and downslope and surface runoff begins. Such overland flow can generate large flood peaks, flashy hydrographs, and altered channel morphology (Meyer *et al*. 2005). This flux in streamflow reflects the integrated pattern of soil dynamics of the land class or streambank affiliated with landform, land use, climate and elevation in the watershed, among the many other variables presented in Figure 2.16.

In general, temporal variation in streamflow is driven by variations in climatic variables (notably precipitation). However, factors controlling the temporal variation in soil dynamics and streamflow are not expected to be the same as those controlling the spatial pattern. While temporal variation in moisture patterns from year to year, or month to month, is much greater than their spatial variation in this small area, the subwatershed to subwatershed variation in biotic, geologic, and drainage factors is perhaps greater than their interannual variations. As land use parameters vary over space, so do rainfall, infiltration, runoff, and erosion properties, for which to account. Site specific analyses on land use and imperviousness have been completed and values employed in runoff equations and estimates. As runoff is primarily a function of land area and rainfall discharge, individual storm events and curve numbers were evaluated at the sub-basin level.

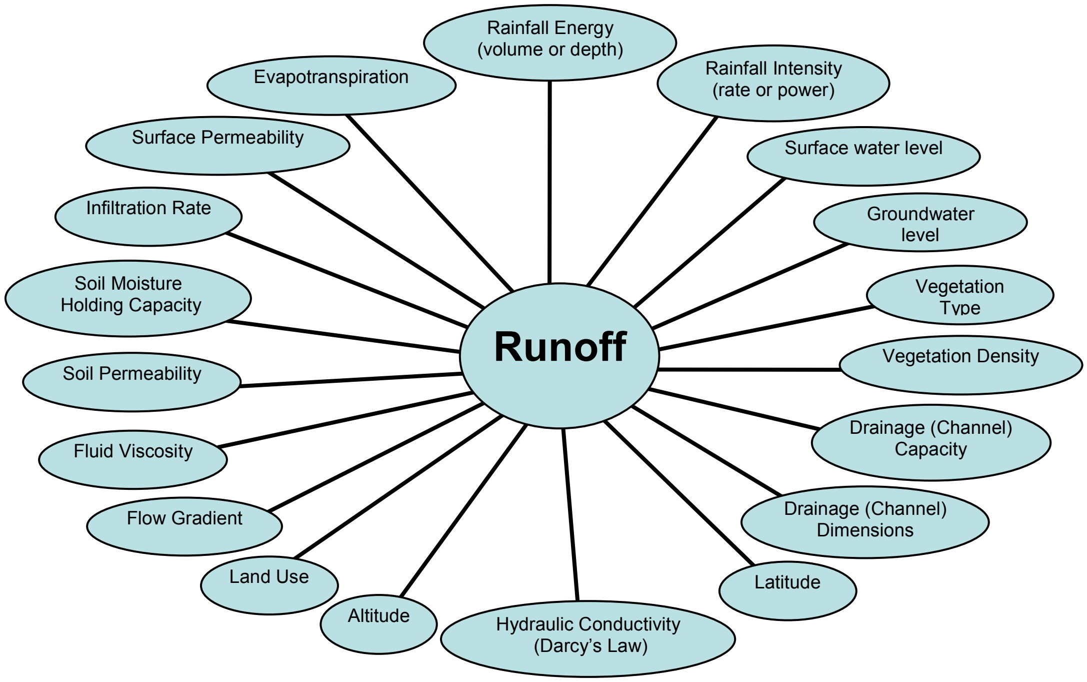

Figure 2.16. Radial diagram of the various natural components involved in runoff rate and volume. The list of components presented is a non-exhausted selection.

Employing the NRCS SCS (Curve Number) method of estimating runoff (NRCS 1986), the volume of water discharged from Citico Creek watershed was determined. Although this method originated as an empirical, event based procedure for flood hydrology, the curve number method has been adapted and used for simulating the runoff behavior of ordinary as well as large rainfalls. As the procedure was intended to be used in ungaged watersheds, the input parameters (curve numbers) are related to soil and vegetation cover and can be estimated with published look-up tables. As such, selection of the various curve numbers for each sub-basin were dependent upon soil condition, land use and land cover. Composite curve numbers were utilized, where each land use and land cover was assigned a curve number then weighted to the respective sub-basin. Runoff for the planning areas was then estimated using the following equations:

$$Q = (P - 0.2S)^2 / (P + 0.8S)$$

Where:

Q = runoff volume in inches
P = precipitation over the watershed in inches
S = maximum soil water retention, determined as: (1000 / CN) - 10

Where CN = composite curve number for various land uses and land covers for soil hydrologic group B taken from USDA NRCS National Engineering Handbook, Part 630 (NRCS 2004).

Evaporation (or evapotranspiration) data is not considered to be a major factor in surface runoff for this watershed due to 1) minimal depression storage, 2) the small size of sub-basins, and 3) the anticipated limited amount of infiltration or standing water due to the great amounts of imperviousness – including impervious channels – creating rapid drainage and downstream flow. Evaporation estimates therefore are omitted from runoff analyses.

Results of the Curve Number Method basic equations above are presented for each sub-basin in Table 2.11. Utilizing different inputs (rain intensity, rain days, and various correction factors), varying end flow results were produced ranging from 100,000,000 to 150,000,000 ft^3/year, or 3 to 4 ft^3/sec. As of time of document production, flow data at any sample site are insufficient or incomplete for any flow-runoff analyses, comparison, or validation. Keep in mind also that since no estimates of baseflow volume or velocity are available, that this "flow" estimate is solely from surface runoff and ignores baseflow which has its origin in groundwater.

Table 2.11. Modeled inputs and outputs used in the NRCS SCS method of runoff estimation for the basins within Citico Creek Watershed.

Basin	Curve Number	Area (ac)	S	One Storm Q(in)	Annual Q(in)	Annual Acre Inches Runoff
2	78.465	369	2.745	0.071	4.329	1597.36
101	80.119	25	2.481	0.081	4.956	123.90
102.01	86.419	161	1.572	0.136	8.347	1343.92
102.02	86.449	89	1.568	0.136	8.369	744.83
102.03	80.843	229	2.370	0.086	5.257	1203.94
102.04	86.908	26	1.506	0.142	8.705	226.32
102.05	76.962	102	2.993	0.062	3.825	390.16
103	78.858	63	2.681	0.073	4.471	281.66
104	80.391	54	2.439	0.083	5.067	273.61
105	77.742	119	2.863	0.066	4.079	485.44
301	80.932	221	2.356	0.086	5.296	1170.39
401	85.457	78	1.702	0.125	7.694	600.13
501	79.037	113	2.652	0.074	4.537	512.63
502.01	81.561	93	2.261	0.091	5.575	518.46
503	83.289	81	2.006	0.105	6.424	520.32
504	73.979	206	3.517	0.049	2.977	613.28
505	76.374	231	3.093	0.059	3.643	841.58
601	89.531	16	1.169	0.179	10.978	175.64
602	89.635	17	1.156	0.181	11.082	188.40
603	81.015	39	2.343	0.087	5.332	207.94
604	89.371	11	1.189	0.176	10.819	119.01
605	79.074	142	2.646	0.074	4.550	646.16
7	87.726	45	1.399	0.152	9.345	420.52

2.5 Water Quality Assessment

Water quality is a composite of physical, chemical, and biological characteristics that vary in space and time and are influenced by natural factors and human activities. Concern about the effects of poor water quality levels on stream ecosystem functioning has encouraged efforts to understand and manage urban development at the national, state, city, and community levels, as well as motivated research efforts and public participation. This section will introduce site-specific baseline water quality parameters and targets towards which the City of Chattanooga is working. Local mechanisms and initiatives have been developed to restore select waterways through local accountability, management, planning, and restoration.

A 6.1 mile section of Citico Creek, from the base of Missionary Ridge to DeButts Railway Yard, is listed on the Environmental Protection Agency's (EPA) 305(b) National Water Quality Inventory Report to Congress as *impaired*. Currently, Citico Creek is listed on the 2006 (and Draft 2008) Tennessee Department of Environment and Conservation 303(d) list for failure to meet designated uses (TDEC 2006b). These waterways are designated as unable to support fish and aquatic life, and recreation at the same level as the ecoregion reference stream. Listed "Causes of Impairment" include: nutrients, low dissolved oxygen levels, pathogens and alterations of streamside. In addition to the 303(d) listing, a portion of the creek has been "posted against human contact" due to elevated fecal coliform bacteria levels. This "posted" stream segment meanders through residential communities, two schools and a municipal recreation facility within the southern section of the watershed (Figure 2.17).

Surface waters in this watershed have been, and continue to be monitored by the City of Chattanooga by means of monthly dry- and wet-weather outfall inspections. Water samples have been collected and analyzed from the main stream near the outfall into the Tennessee River (35°03'13", 85°17'19"; TDEC site CITIC000.3HM; Figure 2.17) since October 2001. Physical and biological parameters monitored and documented include *E. coli*, turbidity, water temperature, pH, conductivity, and dissolved oxygen. Past and current physical and biological monitoring regimes are summarized below (Table 2.12). At time of publication, no nutrient TMDL has been proposed for Citico Creek Watershed so minimal emphasis will be placed on chemical or nutrient composition or sampling for the planning area.

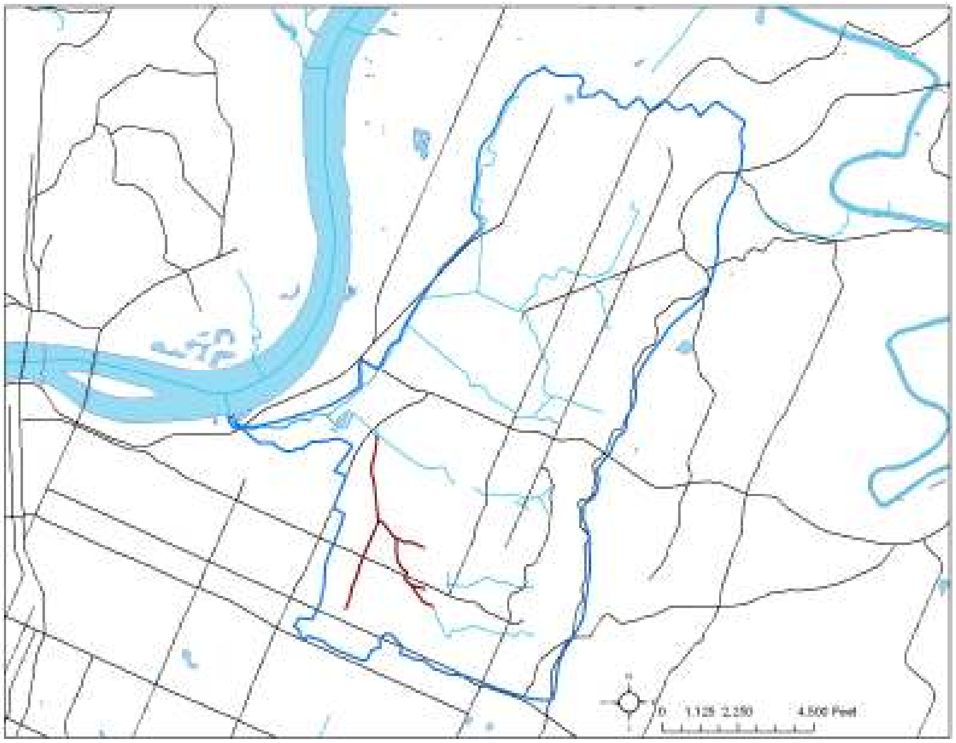

Figure 2.17. Location of Citico Creek segment posted against human contact due to elevated pathogen levels.

To supplement the routine monitoring of the water quality parameters listed above, the City of Chattanooga has also begun a thorough pathogen monitoring program with samples sites scattered in the southern sections of the watershed. Once per quarter, beginning permit year 2007 (October), fifteen sites with various land uses of institutional, residential and open spaces were visited for *E. coli* analysis (Figure 2.18). Additional site identifications from this intensive monitoring regime are defined in Table 2.13 below.

General results from the City of Chattanooga's monitoring program indicate that Citico Creek is a poorly-oxygenated waterway with somewhat alkaline water, at a fairly stable water temperature, with moderately conductive water. Specific data findings are presented below.

Table 2.12. Water quality sampling regime for Citico Creek sample site located at Riverside Drive, Chattanooga (TDEC site CITIC000.3HM). Samples are collected once monthly, or more frequently depending on rainfall amounts. * Numerical samples collected since 2-2004.

Parameter	Unit	Sampling dates	Frequency
Fecal coliform	cfu/100ml	9-2002 to 4-2006	1 / month
E. coli	cfu/100ml	4-2006 to present	1 / month
Turbidity	ntu	2-2004 to present*	≥1 / month
Dissolved Oxygen	mg/l	10-2001 to present	≥1 / month
Conductivity	μS/cm	10-2001 to present	≥1 / month
Temperature	° C	10-2001 to present	≥1 / month
pH	unitless	10-2001 to present	≥1 / month

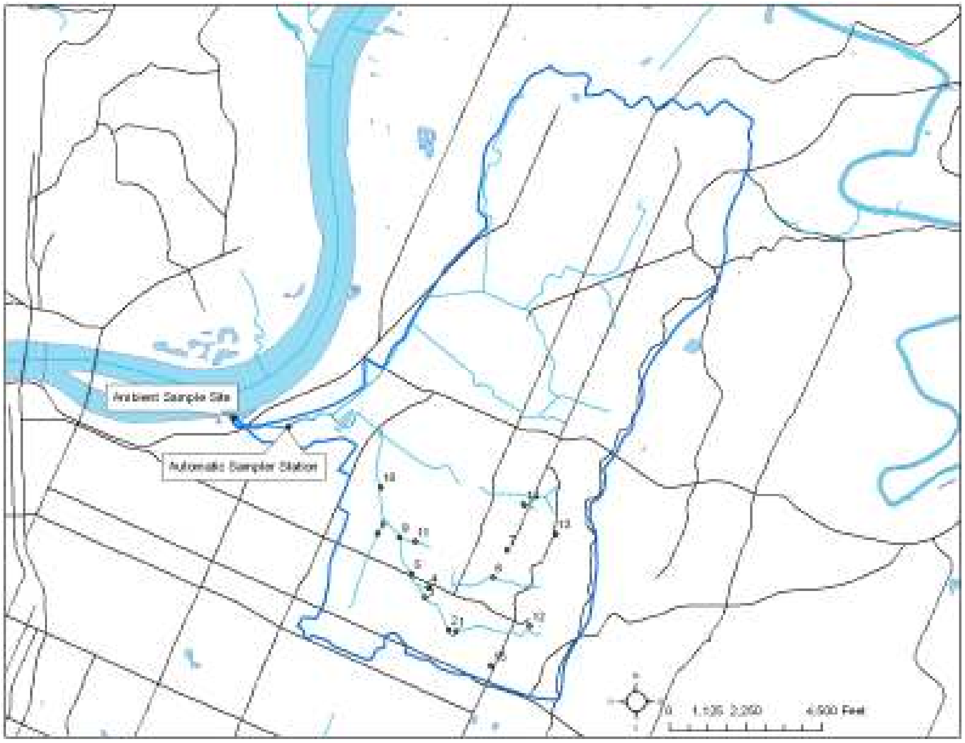

Figure 2.18. Location of the various water quality sampling sites within Citico Creek Watershed. Monthly samples occur at the “Ambient Sample Site”, and periodic pathogen samples occur at the scattered sites in the south.

Table 2.13. Land use information for City of Chattanooga supplemental sample sites within Citico Creek Watershed. NA represents sites not analyzed by the respective agency.

Location	City Number	TDEC MM	Land Use
TN AmericanWater Co. intake, by TN river	Ambient	0.3	Open Space
Wilcox and Amnicola by railyard	TMDL	1.0	Industrial (Railyard)
McConnell and Ivy, across from Parkridge	1	2T0.0	Institutional (Hospital)
Parkridge Hospital	2	1T1.2	Institutional (Hospital)
Willow and 5th, u/s of Elem	3	1T0.9	Institutional
Willow and 3rd, u/s of Elem	4	3T0.1	Institutional
3rd and Orchard Knob, d/s Elem Sch.	5	1T0.8	Institutional
Orange Grove and Derby	6	4T0.5	Institutional
Orange Grove Ctr Park	7	3T0.7	Institutional
Cleveland and Orchard knob, d/s of Carver Rec	8	6T0.1	Open Space (Municipal Park)
Cleveland and Carver, u/s of Carver Rec.	9	5T0.1	Low Density Residential
North Holly and Citico Ave., near Carver Rec.	10	1T0.3	Open Space (Municipal Park)
Cross Drain Under Orchard Knob Ave.	11	NA	Open Space (Municipal Park)
Glenwood Circle	12	NA	Institutional (School)
903 Glenwood Circle	13	NA	Low Density Residential
N. Chamberlain Ave.	14	NA	Low Density Residential
2612 Glenwood Dr.	15	NA	High Density Residential

2.5.1 Physical Parameters

The composition and concentration of particulate matter in an aquatic environment is affected by the source and transport pathway of sediment inputs. The processes of sediment fate and transport have long been analyzed with many inferences suggested. For example, it has been suggested that suspended solids act as the primary transport mechanism for other pollutants and nutrients in waterways through flocculation, adsorption and colloidal action (Ittekot and Zhang 1989, Stone and Droppo 1994). Thus, sediment generation, transport, and diagenesis may likely be directly and indirectly responsible for water quality impairment.

Sediment transport processes include deposition, settling, resuspension, and dispersion. All of these are a function of flow velocity versus time, particle density and size, gravity, water viscosity, water column depth, and the complex dynamics among such factors. An accepted TMDL for Siltation and Habitat Alteration for the planning area reported an estimated sediment loading rate of 1,156 lbs/ac/year (TDEC 2006c). Such loading rates are among the highest for the Lower Tennessee River Watershed. This estimated per acre loading rate equates to over 1,450 tons of sediment exiting the watershed each year. The TMDL requires a 65.4% reduction to 400 lbs/ac/yr (or approximately 506 t/yr) for the planning area.

These sediment loading values were estimated utilizing the EPA supported Watershed Characterization System (WCS) Sediment Tool, which uses the Universal Soil Loss Equation (USLE), sediment delivery equations, and GIS tools. A comparable soil and sediment loss model is presented in Section 3.2, with outputs calibrated to the above TMDL loading rates. The state TMDL does not however provide detailed assessments on source loads or critical areas, and site-specific land uses or land covers have been found to play a complex multi-faceted role in hydrologic and biogeochemical cycles. The additional modeling activity presented in the current document will result in land use specific loading rates, for which land use specific recommendations may ultimately be proposed. Section 3.2 will further define methodology, equations, inputs, and outputs used by the City of Chattanooga water quality modeling activities.

Suspended matter such as sediment (but also other solids such as phytoplankton or organic matter) interferes with the passage of light through the water column - this process is termed turbidity. As a measurement of the scattering of light by particulate and dissolved solids and sediment in the water column, turbidity has the potential to provide an indirect measure of particulate concentration. Size, shape and mineral composition, along with water temperature and color, can significantly affect a turbidity reading. High turbidity is normally associated with rain events when surface runoff transports sediments from the soil to the stream, and when such rainfall energy does not allow sediments to settle along river beds.

Narrative turbidity conditions have been monitored within the planning area since October 2001, and numerical monitoring began in February 2004 (Figure 2.19). Since numerical documentation began, only three samples have been greater than the instantaneous acceptable range of 50 NTUs. However, the turbidity sampling regime for the City of Chattanooga is not weather dependent but rather calendar dictated. As such, no inferences may be suggested concerning sediment transport processes as they relate to turbidity.

Under this same sampling regime, City of Chattanooga water quality technicians have monitored water temperature and dissolved oxygen levels for the single sample site for Citico Creek watershed since 2001. The State of Tennessee declares that any water temperatures greater than 30.5ºC will violate the maximum temperature criterion established for “propagation and maintenance of fish and aquatic life” (TDEC 2004). No single sample from the Citico Creek outfall has exceeded this numerical limit for water temperature, as seen in Figure 2.20.

Low dissolved oxygen (DO) levels were observed at the city sample site for Citico Creek during the sampling period from 2001 to present (Figure 2.21), with several samples less than 5mg/L. Prolonged exposure to low dissolved oxygen levels (less than 5 to 6 mg/L oxygen) may not directly kill an organism, but has been found to increase its susceptibility to other environmental stresses. As a result, DO levels on select dates failed to meet state Ecoregion stream levels (TDEC 2005). These low peaks of DO correspond highly to high water temperature peaks as seen in Figure 2.20 (Regression analysis R^2=0.41, $p<0.001$)

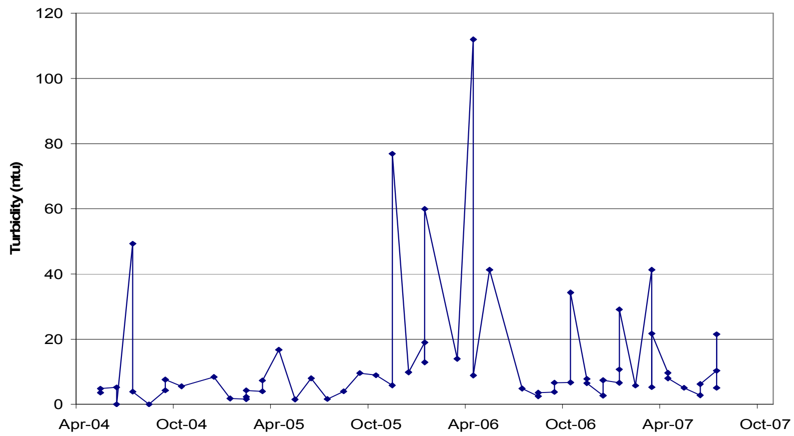

Figure 2.19. Turbidity (in Nephelometric Turbidity Units, or NTU) for Citico Creek sample site near the outlet to the Tennessee River, Chattanooga. Values are from 5-2004 to 9-2007, with the five high and low values excluded.

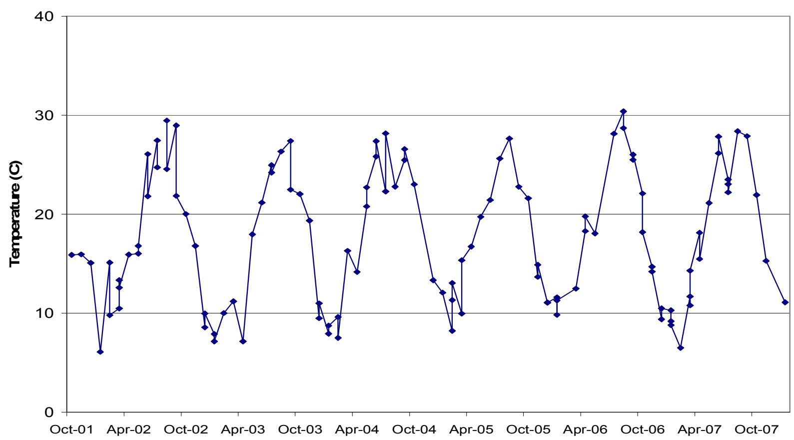

Figure 2.20. Water temperature (in °Celcius) of the Citico Creek sample site, as monitored by City of Chattanooga from 10-2001 to 10-2007, with annual temperature cycles clearly present.

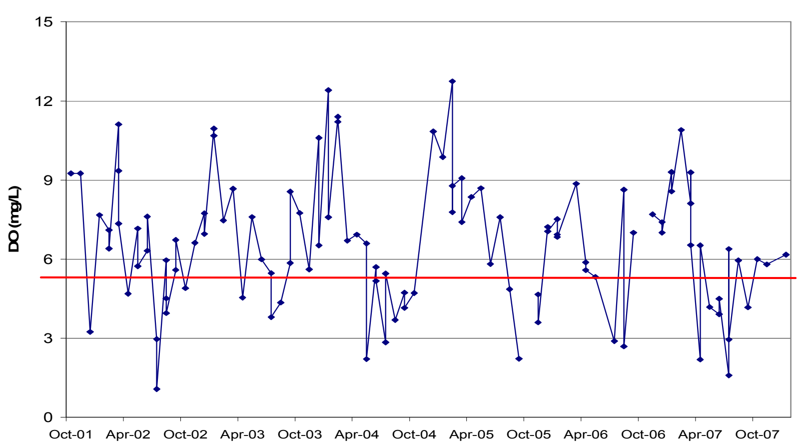

Figure 2.21. Dissolved oxygen levels (mg/L) of the Citico Creek sample site, as monitored by City of Chattanooga from 10-2001 to 10-2007. The solid red line represents the State of Tennessee DO minimum level of 5.0 mg/L.

2.5.2 Biological Parameters

State of Tennessee water quality standards (TDEC 2004) for the *E. coli* group require that the concentration shall not exceed 126 cfu per 100 mL, as a geometric mean based on a minimum of 5 samples collected from a given site over a period of not more than 30 consecutive days. The geometric mean concentration is the best estimate of central tendency of the data and may be used to assess model fit by minimizing the effects of outliers in microbiological data. Individual samples for most state waterbodies can range from 1 to 941 cfu per 100 mL.

The single sample standard, as designated by TDEC was exceeded 2 out of 8 dates at a single sample site within the watershed, dated between November 1999 and November 2004. These data were used by TDEC for construction of load duration curves for *E. coli* (Figure 2.22) and supporting TMDL development. Based on water quality findings in the document, the TMDL proposed a greater than 90% required reduction in pathogens for this site along Citico Creek. Water quality samples since the acceptance of the TMDL for Pathogens have provided consistent *E. coli* counts over time at the given site, with samples markedly lower than the state standard, as seen in Figure 2.23.

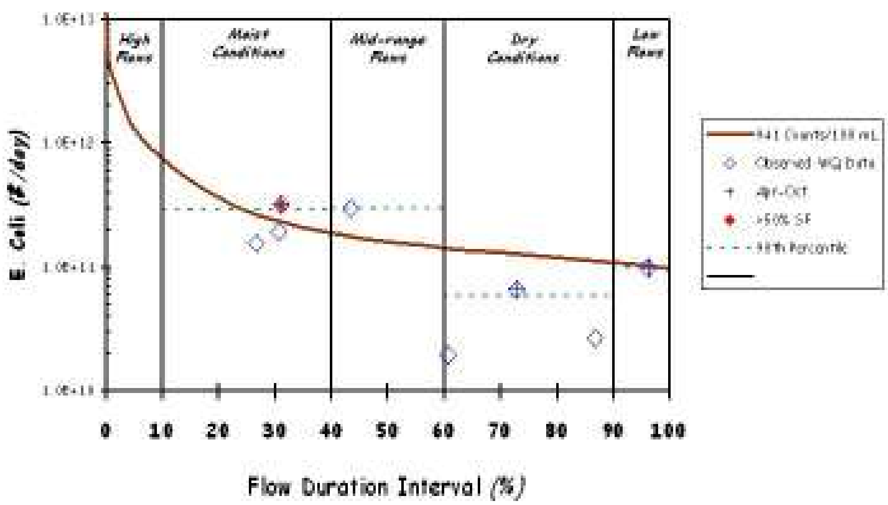

Figure 2.22. Load duration curve for *E. coli* at a single site along Citico Creek; taken from TDEC 2006b. Sample site is located along Riverside Drive, near the outlet into the Tennessee River, with monitoring data from 1999 to 2005.

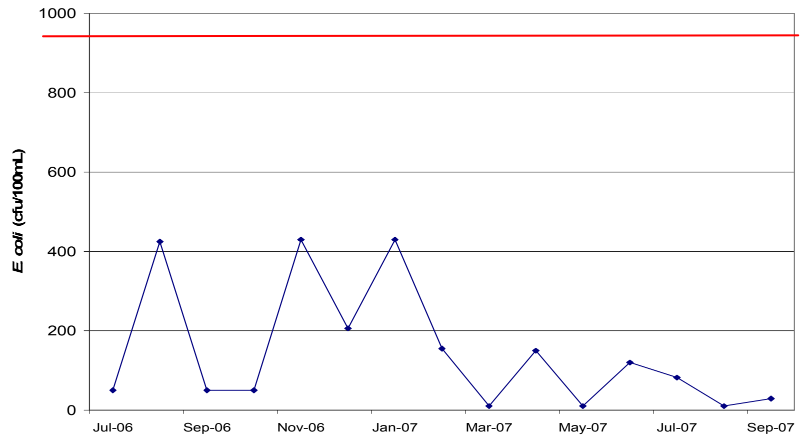

Figure 2.23. Water quality sampling results for *E. coli* in Citico Creek from 6-2006 to 9-2007. The solid red line represents the State single sample standard of 941 cfu/100mL.

As introduced above, supplemental water quality monitoring began in 2007 to provide additional pathogen data for watershed assessments and characterization. Data are presented in Figures 2.24 and 2.25 from October 2007 at the various sample sites identified above. This single data set is presented because 1) this is the most recent set of sample data available at time of document production, 2) this is the most thorough set of sample data available at time of document production, 3) samples and analyses were conducted in accordance with the State of Tennessee's Quality System Standard Operating Procedure for Chemical and Bacteriological Sampling of Surface Water, (TDEC 2004) and 4) the methods employed satisfy TMDL monitoring requirements for pathogens. For these reasons, this set of water quality data will also be utilized in subsequent water quality (pathogen) simulations and calibrations in Section 3.1. Additional data are presented in Figures 2.26 and 2.27 following these monitoring protocols.

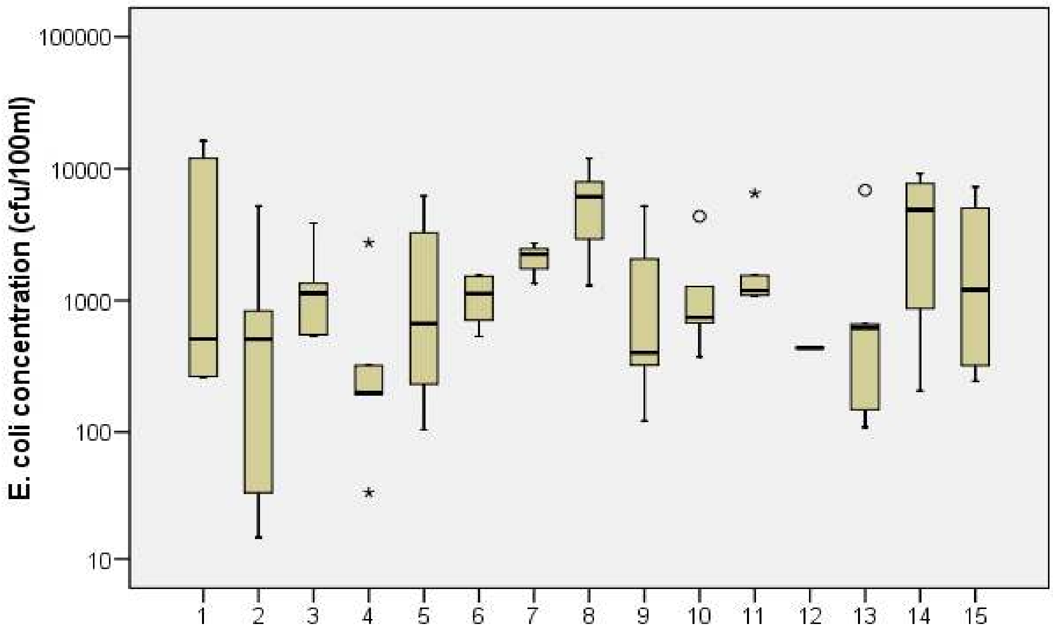

Figure 2.24. Water quality sampling results for *E. coli* from various supplemental sample sites within Citico Creek during autumn 2007. Logarithmic data represent the median *E. coli* level (cfu/100ml) collected and analyzed from 16 sites (see Table 2.13 above), over a 30-day period in October 2007, as defined and set forth by TDEC. Open circles represent statistical outliers (defined here as >1.5 x IQR), and stars are extreme values (>3 x IQR).

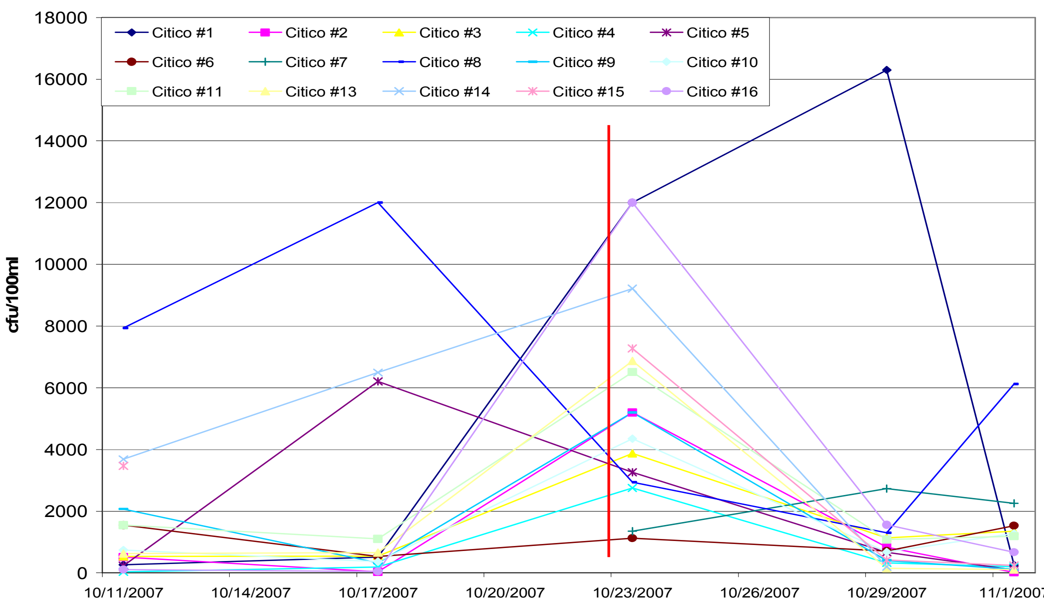

Figure 2.25. Water quality sampling results for *E. coli* over time from various supplemental sample sites within Citico Creek during autumn 2007. Points represent the *E. coli* level (cfu/100ml) collected and analyzed from 16 sites (see Table 2.13 above), over a 30-day period in October 2007, as defined and set forth by TDEC. The vertical line signifies a significant rain event at 2.31 inches.

Spatial and temporal variations were evident in the pathogen sample analysis, as seen in the above figures. Monitoring Site 8, located at the confluence of an incoming tributary into Citico Creek at the municipally operated Carver Recreational Center had consistently high *E. coli* counts, regardless of sample date (or associated precipitation). The geometric mean (the average of the logarithmic values of the data set) for Site 8 during the autumn sample period was 4,673 cts/100mL, nearly twice as high as any other monitoring site for the same period. Monitoring Sites 2 and 4, two highly urbanized sites, exhibited the two lowest geometric mean values of the watershed, while Sites 12 and 13, located near the source springs of Citico Creek, also exhibited low concentrations. At time of document publication, no definitive explanation of spatial variability of monitoring results may be offered. It is highly probable however that such results are a function of land use categories, urbanization, inputs from the sewage and storm systems, the influence of geology, or the combination of any of these.

When evaluating monitoring results over time, it is worthwhile to note that much of the sampling month of October 2007 was very dry, apart from a 2.3 inch rain event on the 23rd of the month. As seen in Figure 2.25 above, many of the individual water quality samples contained low levels of *E. coli* (42 out of 82 were below the state threshold of 941 cfu/100ml). However, during and immediately following the rain event, all of the sites exhibited high pathogen concentrations, suggesting flow related trends. Three sites still spiked during dry periods, suggesting problems not related to rainfall - flow events or trends. One of these suspect monitoring sites is Site 8, referenced above as a consistently high monitoring location. This site along with any others with non-flow related spikes, or any sites consistently high must be evaluated for illicit discharges and subsequent elimination actions to follow.

Such spatial and temporal variability was negated during winter 2008 sample events. Figure 2.26 and 2.27 below show a marked decrease in pathogen counts within Citico Creek Watershed for nearly all sample sites. Both geometric mean values as well as single sample values declined considerably. Monitored pathogen concentrations for Site 8 dropped nearly 95% from autumn 2007 to winter 2008. Similarly, the maximum single sample dropped nearly 50% from autumn to winter, with 61 out of 78 grab samples below the state limit of 941 cfu/100ml. For winter samples, no site had consistently higher *E. coli* concentrations than another.

All sites sampled in winter 2008 followed the same trend over time, with minimal deviation from one another. The range in concentrations was minimal for both site and sample date. A noted increase in pathogen counts was observed following a rain event, further supporting local precipitation-induced or flow-related *E. coli* trends.

Citico Creek Watershed will continue to be sampled quarterly in Spring and Summer 2008 at the pre-established 16 monitoring locations. Additional monitoring will occur at these sites on an annual basis beginning October 2008 through September 2011.

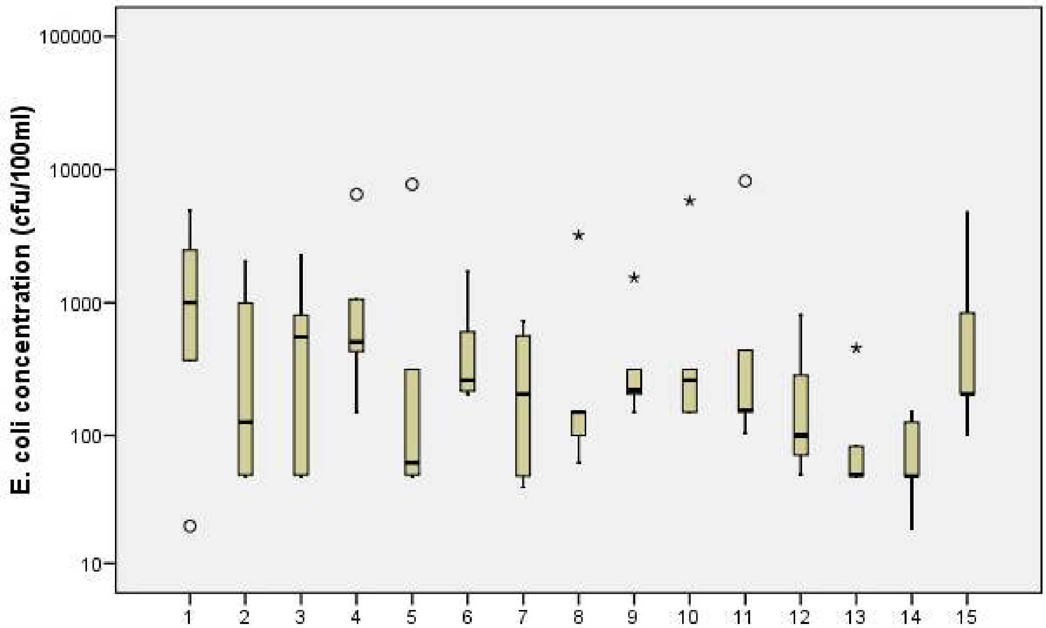

Figure 2.26. Water quality sampling results for *E. coli* from various supplemental sample sites within Citico Creek during winter 2008. Logarithmic data represent the median *E. coli* level (cfu/100ml) collected and analyzed from 16 sites (see Table 2.13 above), over a 30-day period in February and March 2008, as defined and set forth by TDEC. Open circles represent statistical outliers (defined here as >1.5 x IQR), and stars are extreme values (>3 x IQR).

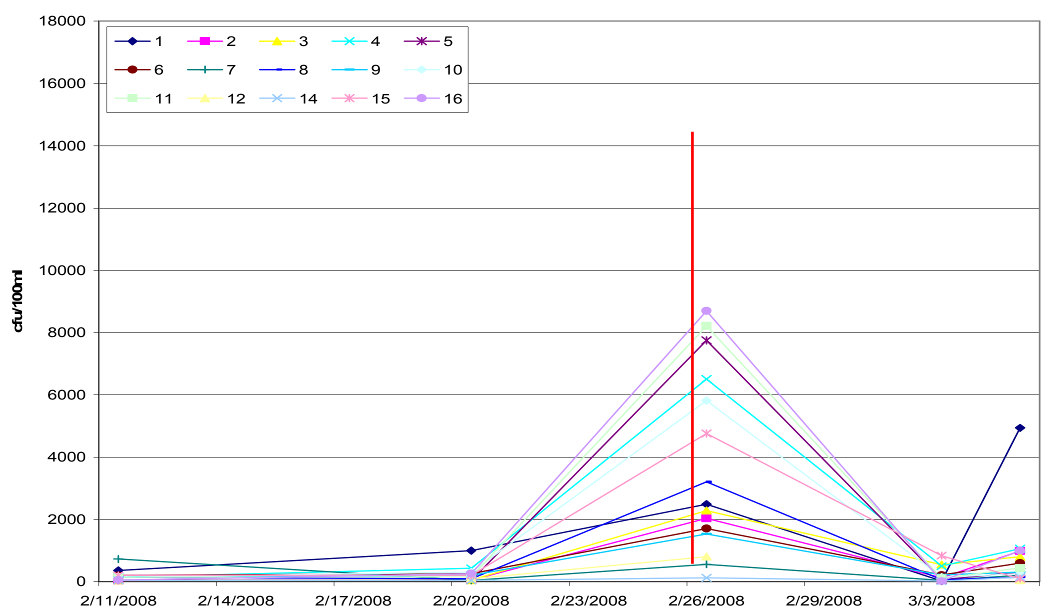

Figure 2.27. Water quality sampling results for *E. coli* over time from various supplemental sample sites within Citico Creek during winter 2008. Points represent the *E. coli* level (cfu/100ml) collected and analyzed from 16 sites (see Table 2.13 above), over a 30-day period in February and March 2008, as defined and set forth by TDEC. The vertical line signifies a rain event at 0.71 inches.

3.0 Causes and Sources of Pollutants

Human activity has directly and indirectly impacted the quality of receiving water throughout history, specifically by the discharging of pollutants and accelerating high volumes of runoff. Greek philosopher Plato noted in his Dialogue of Critias in 360 BCE:

> "There are mountains in Attica, which can now keep nothing but bees, but which were clothed, not so very long ago, with fine trees...while the country produced boundless pasture for cattle. The annual supply of rainfall was not lost, as it is at present, through being allowed to flow over a denuded surface to the sea, but was received by the earth, in all its abundance, into her bosom where she stored it."

Recent environmental concerns are focusing on diffuse sources of pollution due to the significant impact on receiving water, and the progress in managing the various point sources. However, diffuse sources of many pollutants, e.g. suspended solids, nutrients, heavy metals, oil and grease, are released over wide areas and are difficult to measure. As conventional monitoring is often impractical, alternative management techniques are required. Characterizing pollution emission rates using the relationship between land use and runoff water quality is one possible method.

Identification and characterization of natural patterns and processes and the subsequential management measures that control nonpoint source pollution is essential for development of watershed management plans. As this Watershed Characterization Report will hopefully serve as a foundation for a watershed-specific management plan, such identification, quantification, and qualification of such patterns and processes is paramount. To specifically address this need the current EPA “Handbook for Developing Watershed Plans” (EPA 2005) recommends analyzing available water quality and land use data, identifying critical areas, estimating pollutant loads, and implementing appropriate BMPs at these critical areas and pollutant sources.

From this current analysis, one may subsequently estimate pollutant load reductions which may be compared to TMDL required reduction values (load, concentration, or percent). Locating critical areas, however, is complicated in that contaminants may be transported with flow, and water movement over a watershed tends to be spatially and temporally dynamic. Potential interactions among hydrologic, fluvial, and nutrient processes add to this dynamic mix. Additionally, the selection of appropriate BMPs to include along a treatment area involves an assessment made within a variety of disciplines (stormwater engineering, stream ecology, landscape architecture, etc.) in order to account for site specific characteristics, limitations and efficiencies. Such information may be obtained through integration of computational techniques with hydrologic and/or water quality models.

Water quality models attempt to emulate the accumulation, infiltration, and removal of pollutants within a receiving stream. Such applications often rely on general data and inferences on pollution concentrations and reactions in surface runoff and then predict the aggregation through an estimation of runoff volumes. The amount and type of required time, effort, and data in using water quality models depends on many factors, perhaps most importantly the complexity of the model employed. In cases when observed data are not readily available, input data may be collected and collated from literature for similar models and (within reason) for similar landscapes. Conversely, best guesses and verification efforts may be required. Regardless of model selection, four basic steps define the procedure for calculating pollution loads generated by nonpoint sources (Chapra 1997). These include:

- Estimating typical concentrations of each water quality pollutant in runoff
- Delineating these water quality data, defined as estimated mean concentrations (EMC), by pre-defined land use types
- Calculating load from a given area by multiplying the calculated runoff volume from that area with the appropriate EMC value
- Calculating total loads from the entire watershed by summing the loads from all the contributing sub-basins in the watershed

Models may vary in their scope and output capabilities; however, some generalizations of the input data requirements are constant. These include watershed segmentation, drainage network, topography, land use or land cover, and rainfall frequency and volume.

Citico Creek Watershed was delineated into individual land and channel segments that are assumed to demonstrate relative homogeneous hydrologic and water quality responses. Based on both topography and hydrology, the planning area was divided into sub-basins ranging in area from 10.5 to 369 acres. This segmentation provides the basis for assigning similar input or parameter values or functions to where they may be logically applied, such as runoff response or meteorologic conditions. Such delineation may be used to prioritize restoration efforts, efficiently and effectively apply funds, educate stakeholders, and improve implementation of stormwater BMPs.

A number of suitable methods can be used to generate constituent concentrations for use in stormwater modeling. Many water quality models estimate nonpoint water pollution into watersheds based on the input of either event mean concentrations (especially for urban areas) or export coefficients (also referred to as build-up or loading calculations). Event mean concentrations (EMCs) represent the concentration of a specific pollutant contained in runoff originating from a particular land use, reported as mass per unit volume of water (usually mg/L). Export coefficients represent the average total amount of pollutant loaded annually into a system from a defined area, reported as mass per unit area per year. The watershed analysis presented here will evaluate both approaches.

A pathogen (bacteria) model is being employed to estimate bacteria concentrations and suspect sources following generally accepted theoretical equations. Data collected from Water Quality Program initiatives and monitoring programs are being used as model inputs along with general and specific parameters of geology, hydrology and land use. These inputs and concentrations are being referenced with comparable literature and applications from EPA, TVA, and Virginia Tech Center for TMDL and Watershed Studies. The pollutant inventory and assessment for siltation in Citico Creek Watershed is based upon a pollutant loading spreadsheet model originally developed by TetraTech, under an EPA contract. Some precision is lost as a result of model simplification, applicability to the planning area, and current data gaps; however, the approaches remain adequate to be used in decision making at the City of Chattanooga planning level.

The models consists of information on local watershed features such as land use/land cover, physical site descriptions (soil, climate), streambank erosion sites, and current monitoring data that will aid in estimating nonpoint pollution sources. Values of acreage and land management practices are applied to characterize nonpoint sources of pollution, and the impact which they have. Although this adds significant complexity to the data analysis process, the analysis of spatio-temporal variation can allow us to further understand water pollution in natural aquatic systems and to develop more improved management strategies for water resources. The results of this analysis are meant to identify and estimate sources of pollution so as they can be addressed via management (BMP) and/or design (LID) recommendations.

3.1 Pathogen Model

Pathogens, or disease causing microorganisms, are a major concern for managers of water resources. The presence of pathogen indicator bacteria, such as fecal coliforms, *Escherichia coli*, or indicator protozoa such as *Cryptosporidium*, is reported to be the most widespread cause of water quality impairment in the United States (EPA 2005). Common sources of such pathogens include leaking or failing septic systems, leaking sewer lines or pump station overflows, runoff from livestock operations and wildlife, and improperly disinfected wastewater effluent. Fecal coliform bacteria are widely used as indicators of the potential presence of waterborne pathogenic organisms (which cause such diseases as typhoid fever, dysentery, and cholera). In general, *E. coli* is considered a better indicator of fecal contamination than fecal coliforms, since this organism does not survive as long in the environment as other members of the fecal coliform group (Toranzos and McFeters 1997). Research conducted by the EPA further determined that *E. coli* is the best method for assessing the potential risk of acquiring a gastrointestinal illness from recreational waters in freshwater systems (EPA 1986).

Pathogen movement through watersheds, other than that stemming from point source discharges, can be regarded as a diffuse pollution process. As such, the two major processes on an area are that of the buildup of pathogens, followed by the washoff of pathogens as presented in Figure 3.1. The buildup is essentially governed by the amount of fecal material containing the pathogen of concern being deposited by animals or people and the reduction in pathogen numbers by factors such as time, sunlight, temperature, desiccation or predation. The washoff of pathogens then becomes a function (as with most pollutant transport) of the kinetic energy of rainfall dispersing the pollutant and the resulting flow washing the pollutant off the area in question (Novotny and Olem 1994). There are two main components of the water flow in large catchments: surface and sub-surface. Therefore, pathogen deposition, storage, movement and decay occur on both the catchments surface and in the sub-surface.

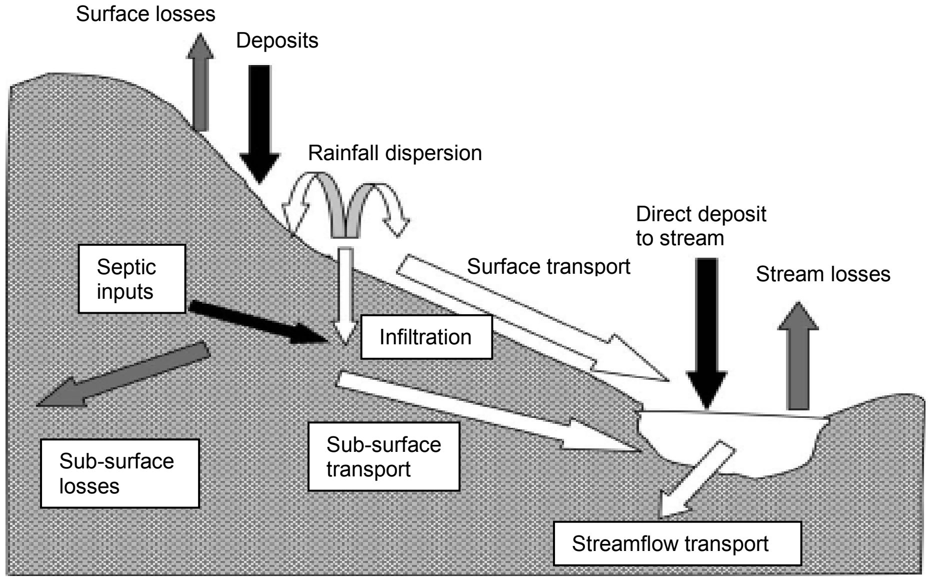

Figure 3.1. Schematic of surface and sub-surface pathogen fate and transport processes.

Concern for public safety, along with regulatory requirements, compels monitoring for pathogen presence and risks. However, there are great temporal and spatial variations due to the characteristics of individual watersheds and hydrologic condition. Such monitoring requires feasible and accurate detection methods for appropriately selected microbes. Water quality monitoring in the U.S. is most frequently conducted for bacterial indicators using the standard membrane filtration or multiple tube fermentation/most probable number methods. These methods are time- and money-consuming, and are therefore not always practical or the first choice for predicting pathogen loads or concentrations. Although pathogen monitoring has been part of the regular monitoring regime in the City of Chattanooga jurisdiction for many years, only a limited amount of state-approved *E. coli* data are available from the recent monitoring that was performed as part of the state minimum monitoring requirements.

An alternative to direct, consistent, and programmatic water quality monitoring is the use of a pathogen loading model designed to simplify the complex and resource-consuming work involved in determining bacterial loadings. Such programs are designed to automate many of the characterization steps, while providing a high level of consistency in data development and processing. Watershed-scale simulation models, such as the Hydrological Simulation Program–FORTRAN (HSPF, Bicknell *et al*. 2000), can help stakeholders and watershed planners make informed management decisions to control such contamination and improve water quality. However, use of such models requires detailed characterization and processing of bacterial source information to generate bacterial loadings to land and receiving waters.

3.1.1 Model Setup

A key step in simulating the transport of bacteria is to determine the total amount of bacteria deposited on the land surface (representing nonpoint sources) or deposited directly in the stream and then deriving estimates of fate and transport. The site-specific fate and transport variables – transport mechanisms to and within the waterbody, length of time it takes to reach the water, death and decay as a function of sunlight intensity, temperature, and radiation, conditions once in the water column, reproduction, etc. - ultimately determine the downstream impacts, making the question difficult to answer. As such, the complexity of tool used is not necessarily a guarantee for prediction accuracy. Modeling or predicting bacteria fate and transport in natural systems is a fairly complex and challenging task for the reasons discussed below.

Predicting the fate and concentration of mobile organisms of any size is a daunting task due to the structure, function, life cycle, and environmental requirements of said organisms. The ability and capacity which bacteria may attach to soil colloids depends on whether or not they are secreting carbohydrates outside their cell walls, or peptidoglycan. The degree to which they secrete such sticky substrates depends on various environmental conditions such as concentration of dissolved organic material (food), availability of electron acceptors (oxygen, nitrate, etc.), temperature, etc. Bacteria are also susceptible to rapid death and decay from environmental factors - largely exposure to UV, which disrupts their DNA/RNA. Single cells suspended in solution (which transport the furthest and fastest) are most susceptible to UV decay, resulting in up to 90% decay within 0.5 to 2 days. When attached as biofilms or clumped in flocs of hundreds, thousands, or millions of cells, lower layers are more protected from UV and decay much more slowly, if at all. Lower layers get less food than higher layers within these flocs, but as the outer layers die, they become the food for the lower layers.

To complicate matters further, bacteria continue to undergo mitosis as their form of reproduction. If these cells have sufficient food (organics or other electron donors), electron acceptors, a nitrogen source so they can manufacture more amino acids and hence proteins, and other necessary environmental conditions such as appropriate temperature and adequate micronutrients (many enzyme systems use iron as a necessary ligand for catalytic function), then they will reproduce. Reproduction rates are generally faster than decay rates (providing an evolutionary advantage) given appropriate environmental conditions.

To fit the complexity of modeling these natural organisms, Water Quality staff have employed the adaptive use of various software tools designed to simplify the complex and time-consuming work involved in determining bacterial loadings. Many watershed modeling tools exist to characterize and quantify bacteria loadings over a given area, and the current effort integrates the resources and methods of three of them. This approach attempts to characterize bacterial loads as they are spatially and temporally distributed, organizing and processing source data to calculate land and stream loadings. The integration of the separate tools required deliberate procedures to automate many of the characterization steps, while providing a high level of consistency in data development and processing.

Three bacteria loading models were referenced and employed in this analysis including the EPA developed Bacterial Indicator Tool (EPA 2000), the Bacteria Source Load Calculator from Virginia Tech (BSLC, Zeckoski *et al.* 2005), and a similar tool developed by TVA (not yet published). All of these are spreadsheets that systematically estimate the bacteria contribution from multiple sources. By default, the Bacterial Indicator Tool was enabled for fecal coliform; however, the tool was adapted for *E. coli*, when the necessary bacteria production information was available. The spreadsheets estimate the monthly accumulation rate of bacteria on various land uses (cropland, forest, built-up, and pastureland), as well as the asymptotic limit for that accumulation considering runoff from these land uses. The models also estimate the direct input of fecal coliform bacteria to streams from grazing agricultural animals and failing septic systems, although neither inputs were necessary for Citico Creek Watershed.

3.1.2 Required Input

Most models begin with land use/land cover classification originally derived from remote sensing techniques used to acquire and interpret aerial photography and develop the pollutant inventory and atlas. Aerial photographs were obtained February 2006, although scattered (re-)development has occurred in the planning area. Whenever possible, the photographic interpretations offered for the study area were referenced with site visits throughout the restoration process. These visits also provided observations of the relationships of terrain, land use, and stream network.

Upon successful completion of land use analysis, classification and input, the following information was established from Section 2.0 and input in to the pathogen loading spreadsheet structure:

- Event mean concentrations (EMCs), production rate, or accumulation rate for each land use
- Rainfall and runoff (Q) estimates taken from Table 2.11
- Wildlife densities for forest and open space in the area (urban land is assumed not to have wildlife)
- Domestic animal densities for high- and low-density residential
- Number of failing sanitary sewer structures in the study area as taken from the Sewer Lateral Assessment Program (SLAP) in Section 2.3.2

A watershed is a very complex system that cannot be feasibly represented without some simplifying assumptions. Therefore, the present approach incorporates many assumptions into its processing. EMCs, production rates and accumulation rates were derived and referenced using American Society of Agricultural Engineers (ASAE 1998), Metcalf and Eddy (1991), Crane and colleagues (1983), EPA BASINS Pollutant Loading Estimator (PLOAD; EPA 2001), best judgments, and consultation with local and regional model developers (CH2MHILL, TVA, UTK and City of Chattanooga staff).

Bacteria loading from forest and open space lands were estimated based on wildlife populations in the watershed. Wildlife species with quantifiable numbers include raccoon, beavers, and ducks; although other fowl and bird species are likely present, but too transitory. For each subbasin, the population of each species was estimated from the acreage of suitable habitat and population density per unit area (Table 3.1). Fecal coliform production rate for each species was needed in conjunction with the population to calculate total load. Domestic animal density, population, and load estimates were derived in the same manner.

Table 3.1. Bacteria loading values from wildlife and domestic animals input in to bacteria model. Values stem from references noted in text.

	FOREST Density/sq mile	FOREST Density/acre	Fecal count (ct/animal/day)	FC/acre/day
Ducks	5	0.0078	2.43E+09	1.90E+07
Beaver	5	0.0078	2.50E+06	1.95E+04
Raccoons	16	0.0250	5.30E+07	1.33E+06
Dog	100	0.1563	2.27E+09	3.54E+08

Most bacteria loading models have been developed for agriculture areas, for which the presence of septic systems have been accounted and quantified. As Citico Creek is almost entirely urban, figures from the abovementioned SLAP were used in appropriate places. Fecal loading was determined by multiplying the average household occupancy rate for the watershed (2.6 persons per household) by the per capita fecal coliform production rate of 1.95×10^9 cfu/head/day. A total count of 768 sewer anomolies was determined through the City of Chattanooga SLAP, and later partitioned into appropriate subbasin.

The sanitary sewer fecal count per subbasin was then derived with the following equation:

Load = Anomaly x Density x Flow x 24

Where:

Load	= Mass load (counts per day)
Anomaly	= Number of anomalies found via SLAP
Density	= People per household, estimated at 2.6
Flow	= Septic flow, estimated at 70 gal/day/person, or 157.8 ml/hr/person
24	= hrs/day conversion

As introduced above, some degree of natural die-off should be expected of organisms such as pathogenic bacteria or protozoa. Similarly, one may assume that only a fraction of watershed pathogens will ultimately deposit in a waterway via natural routing such as overland runoff. For example, urban runoff models typically assume that a uniform runoff of 12.7 mm/hr will wash away up to 90% of a pollutant from an impervious surface (Metcalf and Eddy 1991). These fractional values were considered when deriving total pathogen counts for a given subbasin.

3.1.3 Model Calibration

A model is a simplified conceptualization of a complex, often chaotic system, which is often characterized by highly variable behavior in time and space. If sophisticated, process-based model concepts are used, they can only be parameterized and driven with significant parameter and data uncertainty due to lacking input data. If conceptual models are used, then the simplified model structures may cause a large uncertainty of the model results. As such, no model, particularly those associated with natural systems, can ever provide a perfect realization. Indeed, it can even sometimes be difficult to quantify the degree of uncertainty in input data, model structure, or model parameterization. Taken together, these uncertainties inevitably lead to considerable uncertainty in model output.

Model uncertainty may be defined as the deviation of the model output from the actual responses of the ecosystem. Scientific uncertainty is present in all ecological modeling and risk assessment; and acknowledging and identifying these is critical for the most appropriate utilization of output. Given the relative simplicity of simulation and loading models in comparison to the complexity of nature, it seems reasonable to question the legitimacy of any mathematical expression of natural patterns and processes. Uncertainty should not prevent stormwater management decision making, but rather it should provide structure to the analysis and present inferences in an appropriate way.

Regardless of the complexity of the model, or the model inputs, residual uncertainty due to natural variation, lack of sufficiently high quality or misrepresentation of data or measurement error will occur (Figure 3.2). This means that extremes are likely underestimated, such as the tail area of a distribution curve. Temporal and spatial scale issues are critical components of any watershed analysis, and as we upscale in either category, processes become increasingly complex. The level of expected accuracy of a given model must be tempered by the complexities of the land use characteristics, drainage patterns, the quality of available data, and water management activities. As such, a certain degree of tolerance of uncertainty must be agreed upon by stakeholders.

Water quality simulation models tend to concentrate on the mathematical expression of theory, likely as a consequence of 1) a belief that the theory is well understood and may be adequately expressed mathematically, 2) limited available data to perfectly fit and evaluate models, 3) limited resources to collect or analyze additional data, and 4) scientific interest and challenge (Reckhow 1994). For these reasons, it is recognized that model coefficients and reactions are not intended to be constants, or appropriate for every system. It is therefore important to calibrate a model and validate its results against field data to increase confidence in predicted results. In this analysis, temporally and spatially distributed water quality data are needed to achieve this purpose.

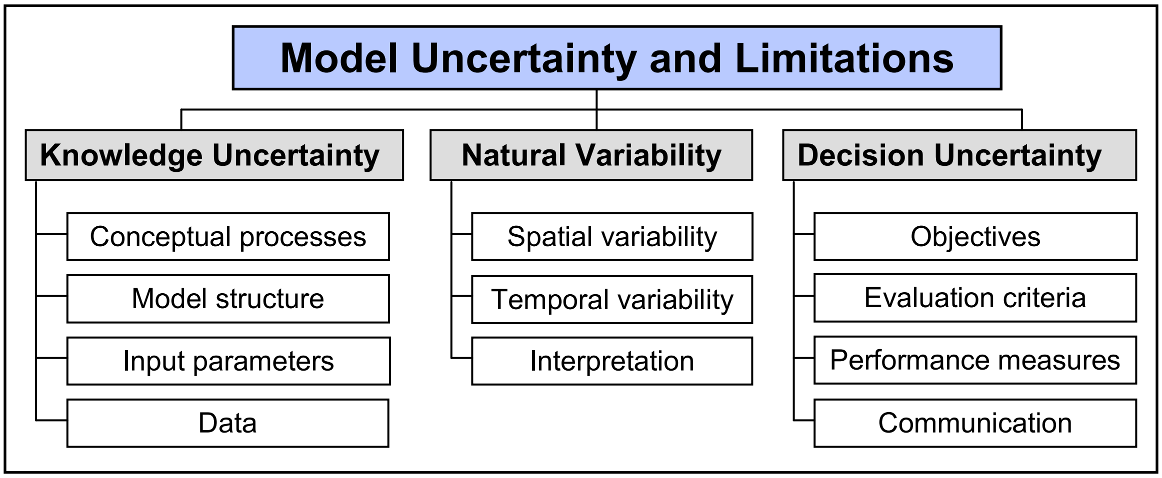

Figure 3.2. Origins of model uncertainty and limitations. Modified from Baecher *et al.* 2000.

Once per quarter, beginning October 2007, fifteen sites with various land uses of institutional, residential and open spaces, were visited for *E. coli* analysis (Figure 2.18, Table 2.13). Field monitoring data collected and analyzed autumn 2007 were utilized for the pathogen model calibration analyses, and referenced with winter 2008 data (cf. Section 2.5.2). The monitoring sites were attributed to their respective subbasin nomenclature. Modeled results were then measured and regressed against geometric mean concentrations from the subbasins. Linear (or first-order) uncertainty analysis (regression) has the advantage that it can be implemented with virtually no computational burden. The results of such an analysis can be extremely useful for assessing parameter uncertainty in a relative sense, and ascertaining the degree of correlation between model parameters. Internal model parameters were then adjusted to maximize R^2 within bounds of realistic relative values and get slope close to one.

As the BSLC Manual succinctly states (Zeckoski *et al.* 2005), modeling software of any capacity should “not eliminate the need for baseline data collection” such as land use distribution and livestock, wildlife, and human population estimates. The methods used to inventory sources and determine the type and distribution of land uses within the impaired watershed are critical to the source characterization process, and are an important first step in effective modeling. A continued and consistent water quality sampling regime should be applied to the planning area to take into account changes in temporal values due to changes in policy and technologic evolution in structural BMPs, which could both be significant impact factors on nonpoint source pollution.

3.1.4 Current Concentration Estimates

After referencing observed *E. coli* values analyzed from autumn 2007, site visits, and consultation with city officials, estimated concentrations were evaluated. The spatially concentrated monitoring data did not allow substantial spatial analyses to be developed, although simulated concentrations matched observed values relatively well. Calibrated regression analysis for the two resulted in an adjusted R^2 of 0.786; ($y = 0.3683x + 967.39$, $p = 0.019$; Figure 3.3) which is well within the realm of reasonability for water quality models. These values represent subbasins in the southern section of the watershed only. However, as noted in Section 2, these areas are considered high-priority or highly impaired by State and City of Chattanooga officials.

Land uses identified and classified as high-density residential produced the greatest estimated pathogen concentration (Figure 3.4), likely stemming from failing private sanitary sewer lines, compromised city-owned main sewer lines, and any associated domesticated animal waste. Commercial, industrial, and institutional sites are estimated to produce low concentrations due to the nature of the limited number of pathogenic inputs to such a site. Undeveloped and forest lands are estimated to contain minimal concentrations of pathogens.

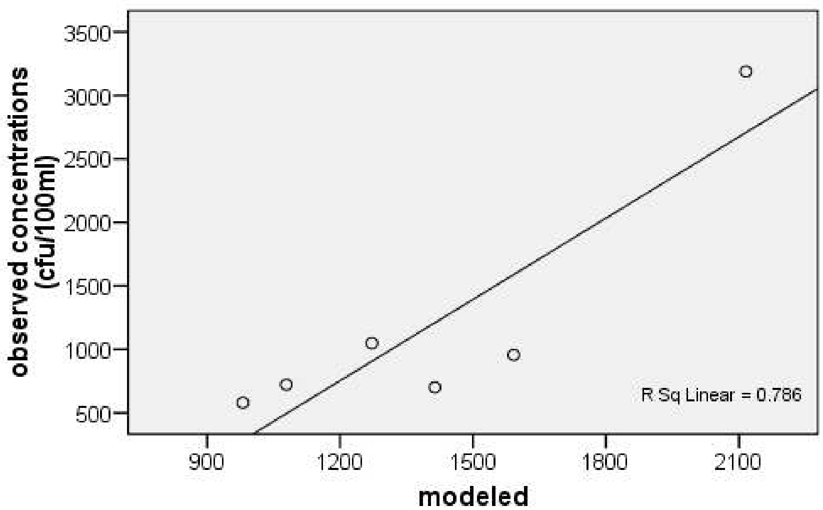

Figure 3.3. Comparison of modeled versus observed *E. coli* concentrations (cfu/100ml) from select southern subbasins of Citico Creek Watershed. Observed values represent geometric means of 5 samples collected over a 30-day period October 2007, then referenced to the respective subbasin. Modeled estimates follow inputs and definitions presented in the text.

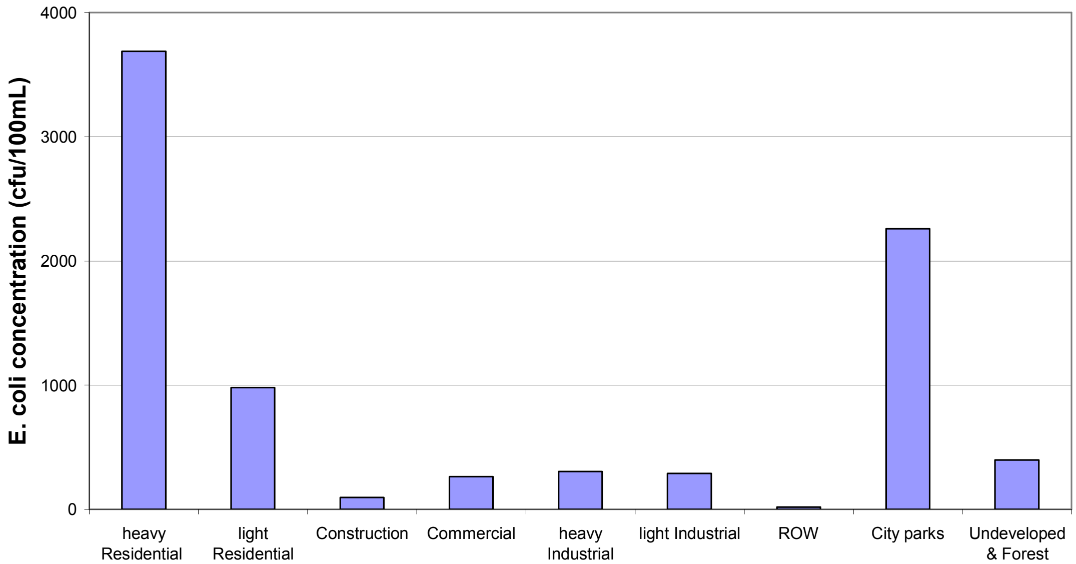

Figure 3.4. Estimated *E. coli* concentrations (cfu/100ml) for land use classes within Citico Creek Watershed. See Section 2.0 for land use classification.

As these various land uses and land classes collectively comprise a basin, Figure 3.5 provides modeled pathogen concentrations for select subbasins. As southern subbasins are comprised of dense communities of residences, these areas are estimated to contain high concentrations of *E. coli.* These same areas ranked high in initial Illicit Discharge Potential desktop analyses conducted previously by Water Quality personnel, and are also posted on site against human contact due to elevated pathogen levels, as regulated by TDEC.

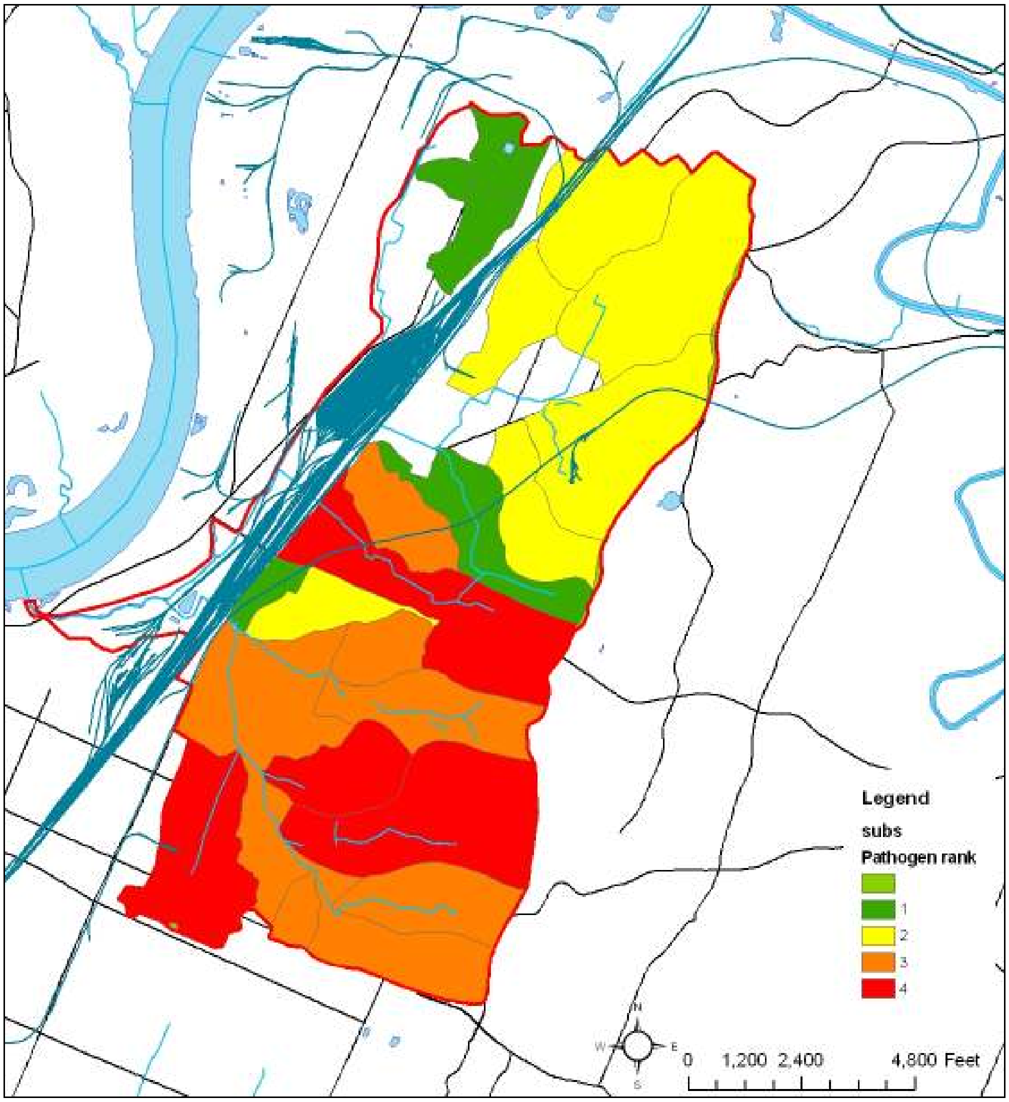

Figure 3.5. Estimated *E. coli* concentration ranking for select Citico Creek Watershed subbasins. Values are modeled estimates following inputs and definitions presented in the text. Ranking 1 = 0 - 471 cfu/100ml; 2 = 472 – 941 (State of Tennessee maximum allowable concentration); 3 = 942 – 1412; 4 = > 1413.

3.2 Siltation Model

Suspended sediment (or small soil colloids suspended in water) is a very useful indicator of active erosion in a particular basin. Suspended sediment concentrations are very sensitive to landscape disturbance, and its conceptual simplicity as a measurement tool gives it broad appeal. The primary problem with using suspended sediment as a monitoring tool is its inherent variability. Suspension of load types depends on water constituents, water velocity, bed material, and stream characteristics, among others. Representative samples are difficult to obtain, and suspended sediment samples vary tremendously over time and space.

Biogeochemical and hydrodynamic models have increasingly been used to quantify and track local and regional sediment budgets in order to determine whether specific areas are sources or sinks for these pollutants. These local assessments, such as those of a residential community or a forest stand, significantly contribute to the comprehension of ecosystem functioning by further qualifying nutrient cycling and sediment transport. Such models vary considerably in their input needs, rigor of process, spatial and time scale, level of analysis, time commitment, and output capabilities. City of Chattanooga Water Quality Staff have chosen the Spreadsheet Tool for Estimating Pollutant Load, or STEPL 4.0 model (EPA 2006) to identify critical land uses and quantify pollutant loads.

3.2.1 Model Setup

As stated in the EPA-STEPL User's Guide, the program provides a user-friendly Visual Basic interface to create a customized spreadsheet-based model in Microsoft Excel. It employs basic algorithms to calculate and estimate nutrient and sediment loads from different land uses and the load reductions that would result from the placement and/or implementation of various BMPs, including LID practices for urban areas. It computes surface runoff, nutrient loads, and sediment delivery based on various land uses and management practices. The land uses considered are high- and low-density residential, commercial, industrial, institutional, roads, disturbed sites, open space, and forest, as identified and defined in Section 2.2. For each subbasin, the annual loading is calculated based on the runoff volume and the pollutant concentrations in the runoff water as influenced by factors such as the land use distribution and management practices.

Figure 3.6 shows the overall spreadsheet structure of STEPL. It is composed of worksheets for input and output interaction with the user as well as hidden worksheets to handle intermediate calculations. The input data include soil characteristics, precipitation data, land use areas, irrigation amount/frequency, and BMPs for simulated watersheds, among others. Other input options are available in this modeling software, but were beyond the scope of the present sediment modeling exercise. When local data were available, certain default values were modified or overridden, including values for USLE parameters, soil hydrologic group, nutrient concentrations in soil and runoff, runoff curve numbers, and detailed urban land use distribution.

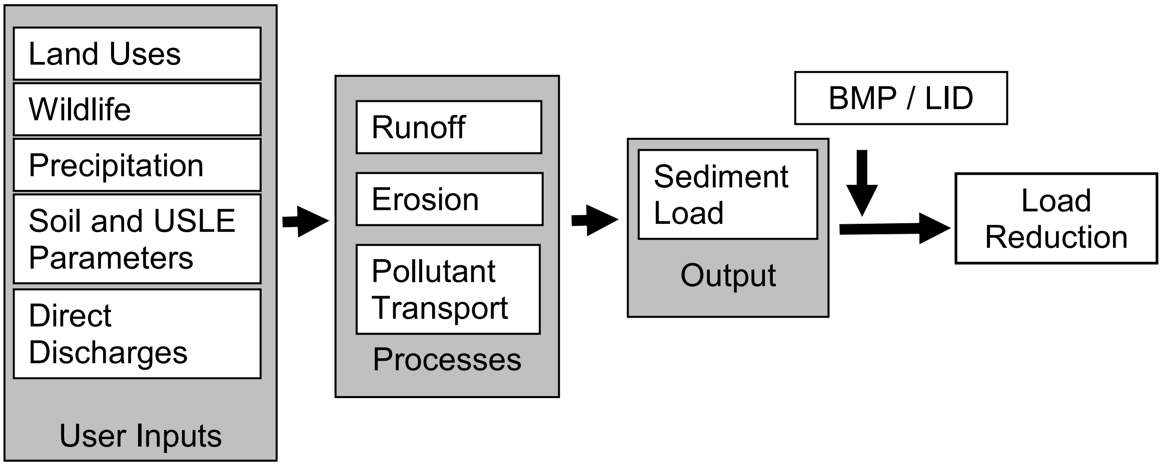

Figure 3.6. Structure of the selected water quality model STEPL, used by City of Chattanooga Water Quality Staff. Figure is adapted from EPA 2006.

Sediment concentrations (inputs) were based on literature values and calibrations to water quality data in previous studies of similar nature. Pollutant loads and load reductions are automatically calculated for total nitrogen, total phosphorus, biological oxygen demand (BOD), and sediment. For these reasons, STEPL has been utilized for various watershed plans and is an accepted model for EPA and State of Tennessee funded projects utilizing grant funds falling under Section 319 of the Clean Water Act.

In general, annual loading models have a great deal of utility, but also a lot of limitations. They can provide a useful estimate of loading rates and sources, but they are difficult to calibrate in a meaningful way, so the subjectivity in parameter estimation can have a big impact on the results. They also ignore or roughly estimate many watershed processes, do not really account for in-stream transformations, and can provide minimal, if any, information about concentration peaks or variability. In developing water quality models, small river basins pose specific problems due to data scarcity, lack of major investments as a consequence of their perceived minor importance, and the large number of diverse inputs, especially if they flow through densely populated and urban areas.

While large modeling software packages attempt to account explicitly for many of these processes, and provide routing and concentration time-series output, it is often difficult to adapt or justify major water quality models, such as those promoted by EPA (QUAL2E, QUAL2K, SWAT, BASINS, WASP6). These programs inherently require a lot more data and a lot more time to set up, which often require more specific information regarding the water system than is available. In these cases, it makes more sense to apply *ad hoc* simple models in order to derive the crucial information about the water quality and ultimately become part of the management and decision systems.

These complex simulation models may be used to address a variety of water quality problems at the watershed scale with increasing numbers of input and output parameters required. An increasing number of process parameters combined with inclusion of more model outputs in the performance evaluation may lead to problems in parameter identifiability. For example, the WEPP model (Flanagan and Nearing 1995) requires as many as 50 input parameters which can cause the problem of equifinality (the condition in which different combination of model parameters lead to similar output). Similarly, robust watershed models such as EPA supported BASINS (EPA 2001) can take months to develop complete files and useable output, resulting in emphasis placed on model development rather than water quality improvement.

There is so much inherent uncertainty in other aspects of the watershed improvement process (amount of load reduction necessary for delisting [especially where causes are inferred from the condition of the macroinvertebrate community], the effectiveness of treatments, participation rates, actual installed costs, etc.) that all stakeholders usually really need is a reasonably good idea of the primary sources and a general idea of how much treatment will be required to get the desired load reduction. Adaptive management over the life of the project keeps the work on target. For these reasons, spreadsheet modeling is adequate for most purposes.

3.2.2 Required Input

Land use acreages obtained following the methods presented in Section 2.2 were used to estimate soil loss, which is generally a function of soil, vegetation, and topographic characteristics, as they integrate to influence runoff (Figure 2.16). Soil loss was calculated for select land use classes (open space and forest) identified in the land use inventory. The amount of soil loss estimated was the total potential soil movement for the feature class via detachment, transport and deposition, based on the Revised Universal Soil Loss Equation (RUSLE; Renard *et al*. 1997) originally developed by Wischmeier and Smith (1978). The equation used for estimating average soil erosion for the planning area is expressed as:

$$A = R \times K \times LS \times C \times P$$

Where:

A	= average annual soil loss in tons per acre
R	= Rainfall intensity factor; 30-yr monthly average from nearby Lovell Field was used, referenced with RUSLE2 software default values
K	= Soil erodibility factor; a weighted average for all soils located in watershed was used (see Section 2.1)
LS	= Topographic factor, L for slope length and S for slope; inferred from GIS mapping (see Section 2.1) and referenced with RUSLE2 default values
C	= Cover Management factor; referenced from Wischmeier and Smith (1978), previous literature and consultation with local NRCS personnel
P	= Conservation practice factor; a default of 1.0 was used

As the USLE was originally developed at a field scale, depositional processes that occur in overland flow prior to reaching a distant stream channel are often excluded. In other words, once a soil particle is detached from the surface, if the runoff, or hydraulic carrying capacity is not high enough (i.e., the runoff velocity), then a portion of the soil mass will likely be redeposited before it gets to the given reference point. Therefore, it is necessary to reduce the gross soil loss by a fraction. This fraction of sediment yield to total surface erosion is termed Sediment Delivery Ratio.

Sediment Delivery Ratio (SDR) is the ratio of mobile (suspended) sediment that actually is transported to a given point of reference (in this case a waterway) relative to the overall eroded mass. That is, the settling velocity of certain particle sizes may exceed the runoff velocity traveling certain distances from the point of erosion to the point of "release" off-site (i.e., SDR<1.0). Such values are found to be affected by catchment physiography and size, sediment sources, texture, proximity to the channel, land slope and land cover. These characteristics have been utilized in several empirical equations for sediment delivery ratios.

Traditionally, though not always, SDR values decrease with the size of watersheds, thus SDR values were considered and estimated for the individual subbasins. The TMDL for Siltation and Habitat Alteration in the watershed (TDEC 2006c) employs a distance slope-based equation for SDR, after Yagow and colleagues (1998); however this equation was developed for and applied mainly to cropland and pasture areas. Because the USDA area-based equation has been used for many years and has appeared to provide reasonable annual "average" estimates of sediment yield, and because this value will not change from default it can be used as an additional basis for evaluating new practices (i.e., RUSLE C factors) or BMP efficiencies.

The area-based sediment delivery ratio was estimated from the USDA National Engineering Handbook, Section 3 - Sedimentation, Chapter 6 - Sediment Sources, Yields and Delivery Ratios (USDA 1978) as:

$$SDR = 0.417762 \times A^{-0.134958} - 0.127097$$

Where:

SDR	= Sediment Delivery Ratio (unitless)
A	= Area (sq smiles)

Pollutant loads from urban land uses (high- and low-density residential, areas with construction, commercial, industrial, institutional, and transportation) were estimated using a method described by the EPA (1990) using the following equation:

$$M = RainV \times Rv \times Area \times Runoff \times Conc \times 0.00011323$$

Where:

M	= Mass load (tons)
RainV	= Average annual rainfall (inches); 30-yr monthly average from nearby Lovell Field was used
Rv	= Rainfall coefficient (% of events that generate runoff, unitless)
Area	= Drainage area (acres), derived from the land use inventory
Runoff	= Urban runoff (inches), as a function of Curve Number; referenced from NRCS TR55 (NRCS 1986) and National Engineering Handbook, Part 630 (NRCS 2004)
Conc	= Average runoff concentration (mg/L); referenced from previous model inputs and literature parameters, including EPA's National Urban Runoff Study (EPA 1983; Table 3.2)
0.00011323	= Unit conversion factor

Pollutant concentrations (mg/L) were taken from the EPA's National Urban Runoff Study (EPA 1983) in conjunction with local water conditions monitored and analyzed by various local, state and federal agencies. Values were determined based on median and 90th percentile urban concentrations presented by EPA, plus high and low values from on-site sampling to obtain pollutant concentrations presented in Table 3.2. Concentrations applied to the present sediment loading model perhaps vary from other published values based on site-specific criteria which are derived primarily from high water quality sampling data and land class condition, such as area, connectivity, and intensity of impervious cover and/or location and efficiency of structural management practices.

Table 3.2. Select input values for a sediment loading model from urban sources of Citico Creek Watershed. Refer to Section 2.2 for additional land class definitions.

	Commercial	Industrial	Institutional	ROW	High-density Residential	Low-density Residential	Disturbed
TSS conc. (mg/L)	80	125	80	130	120	100	1500
Area (ac)	55.9	316.8	19.9	338.3	423.0	993.9	26.8
NRCS Curve Number	92	88	84	98	85	75	78

Values for streambank erosion and sedimentation rates were estimated from calculations based on the average bank height, recession rates of eroding banks and approximated soil bulk density. Values for each of these parameters were obtained by site visits, default STEPL parameters, and consultation with NRCS using critical erosion rates for the ecoregion. A weighted average of soil textural class from Section 2.1 was applied for determination of average soil bulk density for the various eroding streambank and referenced with the Soil Survey of Hamilton County (USDA 1982). As streambank soil losses occur at and directly in the waterway, no fractional SDR was applied.

As displayed in Figure 2.2, the majority of the watershed contains only three soil series (CdC Colbert-Urban silt-loam, FuE Fullerton cherty silt loam, and SfB Sequatchie-Urban loam, clay-loam), thus the soil bulk density applied ranged from 82 to 86 lb/ft^3, with a weighted average being employed. Average bank height per individual subbasin was obtained utilizing site-specific field values from the SCORE program (Section 2.3.3, Table 2.8). Bank height values ranged from slightly over one foot in highly urbanized subbasins to over three feet for forested areas in the northeast of the watershed. Lateral erosion rates were inferred from site visits and associated SCORE erosion values, as in Table 3.3.

Table 3.3. Lateral erosion (or recession) rate derivations and descriptions used in the siltation model. SCORE tally represents values collected from visual stream surveys conducted by Water Quality staff.

Recession rate (ft/yr)	Category	SCORE tally	Description
0.01 - 0.05	minor	<9	Some bare bank but active erosion not apparent. Some rills but no vegetative overhang; no exposed tree roots.
0.06 - 0.2	moderate	10-19	Bank is predominantly bare with some rills and vegetative overhang. Some exposed tree roots but no slips.
0.3 - 0.5	severe	20-27	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some fallen trees and slips. Some changes in land use features such as fallen fences or realigned roads or trails. Channel cross-section is U-shaped rather than V-shaped.
0.6 +	very severe	>28	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains, and culverts eroding out and changes in land-use features as above. Massive slips or wash-outs common.

As stated in Section 2.3.3 above, erosion potential for much of Citico Creek was found to be highly correlated with channel substrate more so than any other monitored variable listed. As seen in Table 2.9 above, earthen channels give way to greater erodability than concrete or concrete lined channels. As such, urban subbasins with high densities of concrete-lined channels such as those areas in the southern portions of the watershed had low lateral erosion rates (≤ 0.05 ft/yr). Subbasins with high densities of natural, earthen channels such as those in the northeast exhibited much higher rates (0.10 to 0.40 ft/yr).

3.2.3 Model Calibration

The ultimate goal of the planning process is to remove Citico Creek from the Tennessee 303(d) list of impaired waters; this includes exercises in water quality modeling. Given the inherent errors in input and observed data (equipment, sampling, transcription, or statistical errors), and the approximate nature of models in general (parameter sensitivity or output uncertainty), no model will offer absolute loading values. Thus, the entire modeling process should be used as a tool to identify regions and practices on which additional monitoring, modeling, and stormwater BMP implementation should concentrate. This targeted effort will prove to be an efficient approach to reduce pollutants on a watershed scale.

The suggested methodology for siltation or sediment model calibration includes a cross validation, which is especially well-suited for cases where available data are limited (Snowling and Kramer 2001), such as the present effort. Indeed there exist very little measured concentrations to which one may compare modeled concentration, or ultimately load. The basin of interest is a poorly gauged and sampled catchment, and therefore the model predictions are assumed to be uncertain. Although much of the available data for the basin are, on average, in agreement with the general conditions, the first approximation model output was calibrated to TMDL values.

The TMDL for Siltation and Habitat Alteration provides a sediment loading rate of 1,156 lbs/ac/year for the planning area (TDEC 2006c). Select initial STEPL parameters were adjusted to fit this target loading rate. Precipitation data and land use acreages were not modified, as these figures derive from real, measured data. In general, curve numbers are by far the most important (and sensitive) parameter for sediment computations, so judicial modification of these values was minimal. Sediment concentrations were thus the best justifiable parameter to be modified to best fit TMDL loading rates. Relative to TMDL estimates, default STEPL sediment concentrations for urban settings were slightly low. To account for such deviations, sediment concentrations (mg/L) were increased. These adjustments, within reason, were sufficient to calibrate the default modeling exercise to TMDL load approximations.

As noted previously, values for streambank erosion and sedimentation rates were directly derived from field data collection on average bank height, recession rates and approximated soil bulk density through the Chattanooga SCORE program. As such, input values for streambank siltation were minimally altered, if at all, to fit the TMDL load estimated by TDEC. During the stream corridor inventory and evaluation of Citico Creek, it was noted that less than 1% of all streambanks currently utilized streambank protection or stabilization measures, although 25% of the channel is concrete-lined. From this, the process should identify specific sites and stream corridors that should and will be further evaluated and targeted to reduce such loading. To verify SCORE erosion results, it is proposed that additional lateral accretion analyses begin on select streambanks following Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) protocols (see Rosgen 1996 and 2001).

The spatial information of the current analysis was presented in a watershed size of 2,530 acres, although some soil properties may vary at spatial scales of less than 1 meter, such as soil depth (Johnson *et al.* 2000). Accounting for spatial variability of soil properties and processes within the watershed may lead to more accurate predictions of pollutant loading in the study area. Estimating the spatial variability of soil dynamics is difficult, however, because soil properties vary substantially at a small scale, and methods to account for such variability are often prohibitively expensive. Similarly, site-specific BMPs likely do not follow linear and additive trends, so research in scaling is needed to improve the prediction of cumulative effects of land uses.

3.2.4 Current Load Estimates

Employing the STEPL model with land use/land cover data, soil erosion estimates, SDR values and pollutant concentrations defined above, soil loss and sediment delivery values were estimated for the 2,530 acre Citico Creek Watershed. Total sediment load for the planning area is estimated at 1,460 tons per year, or 1,154 lbs/ac/yr. Through model calibration, this value roughly equals the loading rate of 1,156 lbs/ac/yr as defined by the TMDL for Siltation (TDEC 2006c). On an annual scale, discerning pollutant loads using load estimates may be challenging, as pollutant loads have a large weather-driven component of variation. This natural variation arises because load is calculated as the product of concentration and streamflow (or infiltration-excess overland runoff); although pollutant concentration may be a function of flow (that is, high flows may cause high loads but at lower concentrations). An attempt to estimate sediment load by month is presented in Figure 3.7 below, as a function of both precipitation volume and intensity.

The breakdown by land use and land cover may be more useful for analyzing and prioritizing load and loading reductions. Figure 3.8 below displays annual sediment loads and loading rates for Citico Creek Watershed by land class. Annual loads stem from loading rate (ton/ac) derived from the inputs and algorithms presented above, and total acreage; however both values should be considered in detail.

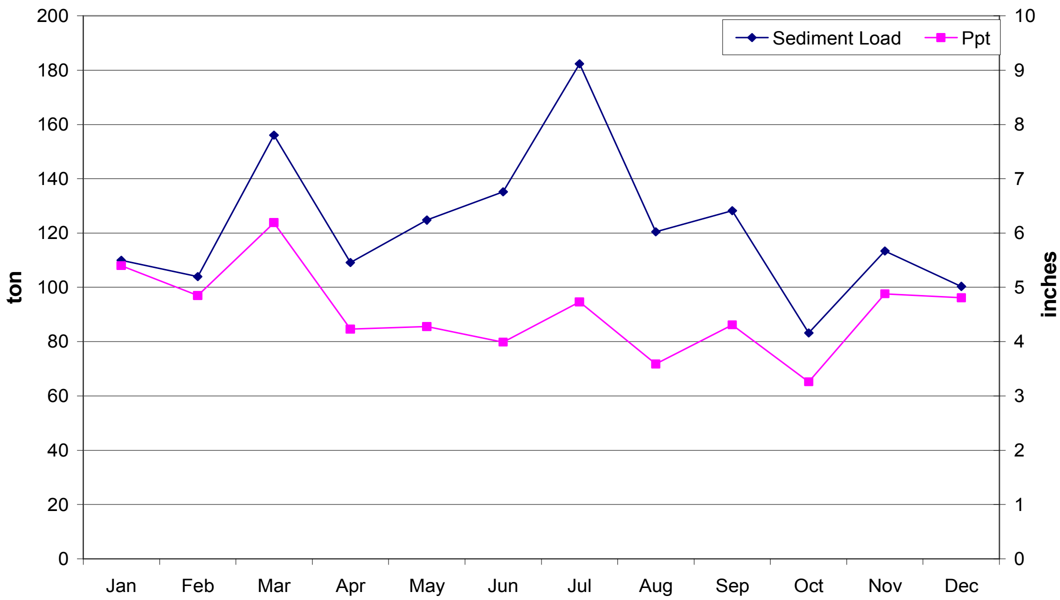

Figure 3.7 Sediment loading estimates (primary axis) and precipitation volumes (secondary axis) for Citico Creek Watershed. Urban source loads are largely a function of rainfall volume, while open space, forest and streambank loads are largely a function of rainfall intensity. Both values derived from National Climatic Data Center (NOAA, Asheville, NC) for nearby Lovell Field (Chattanooga Airport) and local RUSLE default values.

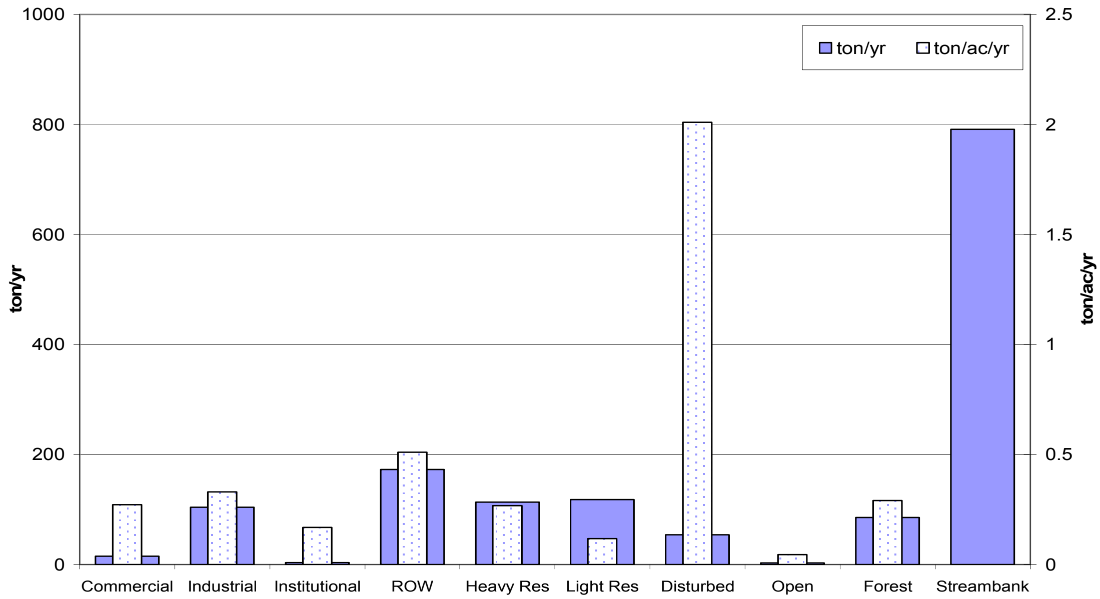

Figure 3.8. Estimated annual sediment loads (tons/year and tons/acre/year) for land use classes within Citico Creek Watershed. Note differing y-axes scales.

Although high- and low-density residential areas account for 56% of the land usages in the planning area (cf. Section 2.2), roughly 18% of sediment loads originate from these sites – due to low per acre rates. Commercial, industrial, and institutional sites account for 15% of the land area, and contribute less than 10% of sediment loads. Conversely, disturbed areas (graded or construction sites) account for less than 0.5% of all the area in the watershed, but due to the high loading rate, the ultimate annual load is 4% of all sediment loads. Open spaces (vacant grassed lots, recreational areas, forests) account for 5% of annual sediment loads, and eroding streambanks account for 50%. Rights-of-way areas contribute 13%. Modeled sediment loads per acre are presented by subbasin in Figure 3.9, allowing for prioritization and targeting efforts for reducing loads.

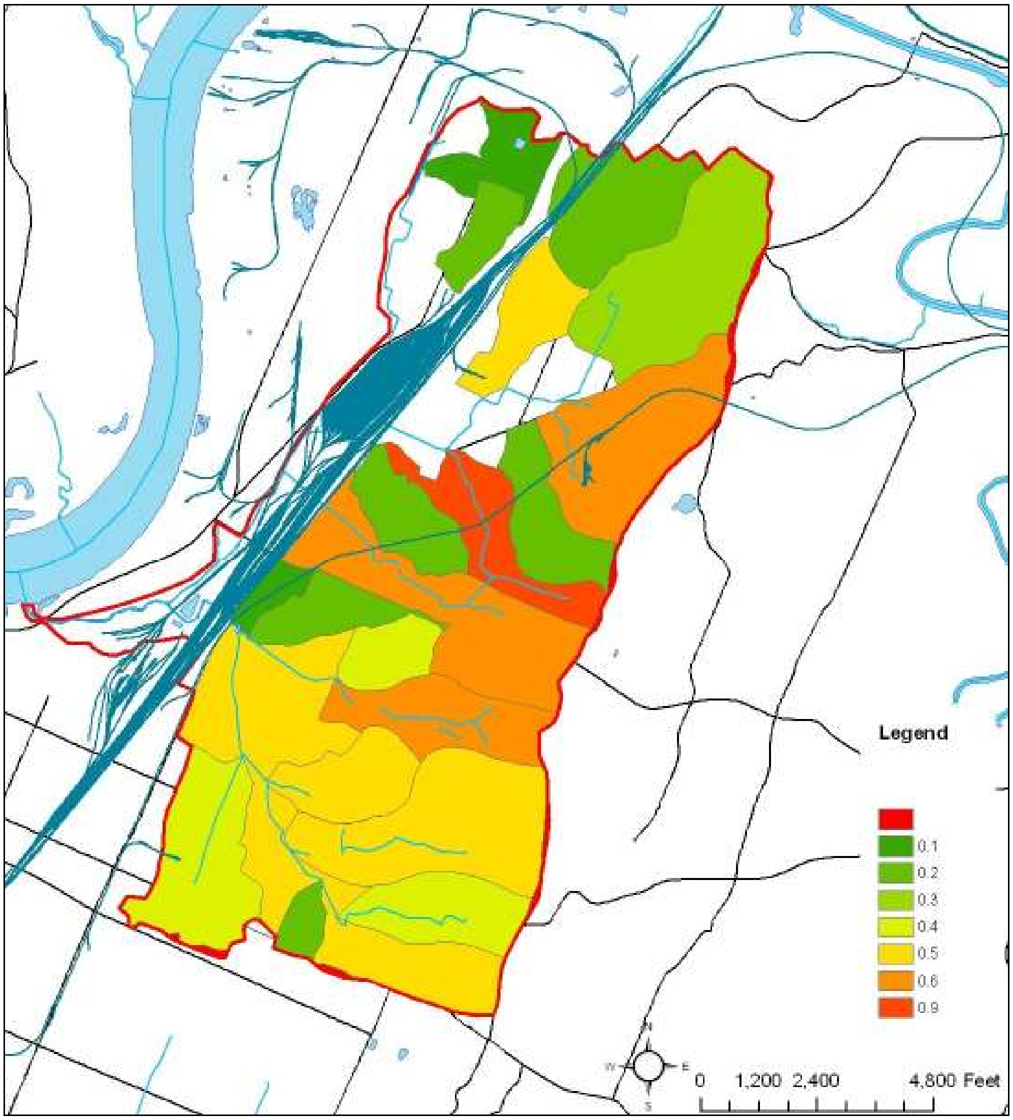

Figure 3.9. Estimated sediment load (ton/acre) for select Citico Creek Watershed subbasins.

4.0 Linking Watershed Analysis to TMDL Implementation

As a result of sections of Citico Creek being listed on the Tennessee 303(d) list of impaired waters, TMDLs were locally developed and federally approved with target values assigned for pathogens and sediment in the planning area. The TMDL is the driving force for regulatory compliance and review and water quality corrections; and as a result, compliance with such numeric values is the ultimate goal of watershed management. In general, pollutant reduction strategies may and should be implemented by processes that first address pollutant sources with the greatest impact on water quality.

Following language from the City of Chattanooga NPDES permit, the Water Quality Program developed procedures and defined the type of data needed to establish water quality and hydrologic characteristics of the priority watershed. To satisfy permit requirements, meet TMDL target values, and to prioritize water quality efforts, personnel identified data gaps, implemented planned procedures, collected relevant data, thoroughly characterized the watershed, and performed water quality modeling to "establish the nature and quantity of nonpoint source pollutants in the watershed" (Section V.C. of the local permit). The present document provides a reasonable database available for such loadings and concentrations, although undoubtedly it is variable regarding fine spatial and temporal resolutions. While there is no one universally accepted approach to the estimation of urban stormwater pollution loadings, a volume-concentration method based on the product of runoff volume and the pollutant concentration provides a simple stochastic modeling approach that has been advocated by many and applied here.

Key model output from this analysis are the catchment severity maps (Figures 3.5 and 3.9), which facilitate the identification of those critical source areas likely to pose the greatest threat to relevant beneficial water uses, and provide priority areas where mitigation measures may be cost-effectively targeted. Patterns in water quality parameters were similar to suspect areas identified in previous analyses and documents, and confirmed suspect source identification. It must be noted however that these maps only estimate the predicted loads or concentrations generated primarily via urban surface runoff (stormwater). Transformation, mobilization, and depositional processes were accounted for as best possible. Such processes, as they occur through the drainage system, may mediate or amplify receiving water impacts, as visualized through condition of aquatic plants, streambank stabilization or erosion, and benthic macroinvertebrate community.

Model predictions, along with monitoring data, indicate a need for substantial reductions of pathogen and sediment inputs to Citico Creek to reestablish local and national water quality standards and compliance. Both approaches have their uncertainties and may be justifiably criticized, which can lead to the conundrum of determining which assessment is more reliable or usable (Qian and Reckhow, in press). Routine monitoring data are often regarded as happenstance data, as a function of unregulated and unpredictable forcing mechanisms, and not designed for inference about the water quality status of an entire basin. In other words, such data may not have adequate spatiotemporal coverage to reflect true conditions. Conversely, models are simplifications of natural systems, and model predictions are limited by structural limitations and theoretical knowledge, as well as by the data used to calibrate the model. It is believed that the two processes and sources of information may be combined to better support the water quality decision making process. Additionally, the two may be used to evaluate compliance and the adequacy of management actions and structures.

Despite the difficulties of source tracing and the episodic nature of many pollutants and polluting events, diffuse urban pollution may, and should, still be addressed by regulatory authorities. Through a combination of modeling, monitoring, and ground truthing, likely sources of pollutants were identified and specific subbasins targeted for corrective measures. Still, because of the uncertainties involved in modeling and monitoring, implementation of watershed restorations must ultimately be holistic with the end result improving in-stream habitat and the benthic macroinvertebrate community. The results of this Characterization and Simulation Report must therefore serve as a major first step in watershed restoration for the planning area.

Linking the Citico Creek Watershed characterization and analysis to TMDL implementation involves identifying appropriate actions to alleviate the impairment and assessing the extent of each implementation action needed. The level of effort required to identify and select the appropriate implementation measures depends on the amount and type of data available from the development of the TMDL, the complexity of the watershed characteristics, and the complexity of the impairments associated. It is believed that the present document provides such information with minimal technical expertise required. The next step in the evolving watershed management process is the development of the nonpoint source management measures that will need to be installed and/or implemented to achieve load (or concentration) reductions; followed by estimates of the load (or concentration) reductions expected for the measures.

For example, in order to reach the loading goals as set out in the watershed-specific TMDL for Siltation and Habitat Alteration, it is necessary to substantially reduce sediment loads from existing residential, commercial, and industrial areas. The present analysis, along with TMDL modeling, estimates an annual sediment load of 1,156 lbs/ac/yr, with a numeric target load of 400 lbs/ac/yr. This target equates to a required 65.4% reduction. Some of the reduction can be realized by improved management practices, such as improved turf maintenance practices or streambank stabilization measures, but much of this improvement must be provided by structural water quality improvement BMPs. Such structures remove sediments by stabilizations, settling, and filtration methods. In the process, other pollutants are removed, and erosion of the stream channels is reduced because of increased storage of stormwater runoff either in ponds or in the soil.

Other mechanisms for sediment load reductions include proper permit enforcement and applications of streambank stabilization measures. Strict compliance with the provisions of the General NPDES Permit for Stormwater Discharges Associated with Construction Activity (TNR100000; TDEC 2005b) is expected to reduce sediment loads considerably. The primary challenge for the reduction of sediment loading from construction sites is the effective compliance monitoring of all requirements specified in the permit and timely enforcement against construction sites not found to be in compliance with the permit. In comparison, modeling of streambank erosion provided high estimates of soil loss which can be attributed to a combination of upland land use and in-stream processes. The results of such processes ultimately lead to in-stream sediment transport and deposition. The STEPL model, supported by the local SCORE program results, shows the stream segments that are potentially vulnerable to excessive channel erosion and subsequent efforts will identify subwatersheds where BMP installation would effectively reduce peak flow and sediment loads. The reduction in peak flow would help lessen the pressures on streambanks and reduce channel erosion.

It is not the purpose of the present document to identify appropriate implementation or corrective measures, but such a successful watershed management plan will almost certainly involve the assessment of other programs, such as measurable goals and milestones, comprehensive and applicable monitoring regimes, and active and adaptable education and outreach initiatives. These items are discussed in detail further below. It would also be appropriate to include the development and implementation of maintenance plans for recommended structural BMPs. As the knowledge base and experience with these issues expands and evolves, complete watershed management plans provide users with the most current water quality management information and strategies.

The City of Chattanooga has invested many years and funds in improving the water quality in the Citico Creek Watershed including initiating a comprehensive approach to building community awareness about local watershed issues and educating and involving targeted audiences in watershed involvement projects. However, with the issues of continued development and aging infrastructure in the watershed concurrent with its continued listing on the TDEC 303(d) list, there is much yet to be done.

A supporting comprehensive watershed plan for Citico Creek Watershed should be developed including implementation schedules with reasonably expeditious timelines, descriptive measurable milestones for determining the implementation of management measures, and perhaps most importantly a set of criteria that may be used to determine whether load or concentration reductions are being achieved. Measurement and evaluation are important parts of the planning process for they can indicate whether or not efforts are successful and provide a feedback loop for improving project implementation as new information is collected and/or obtained. Additionally, if the monitoring and evaluation program displays positive results as they relate to improved water quality, the plan will likely gain support from partnering communities and agencies, as well as local decision makers, and increase the overall likelihood of project sustainability and success.

The collection of water quality information is extremely important as we learn how to address water quality resource concerns. Adaptive management requires that we observe the effects of natural resources management decisions so we can maximize learning and increase the knowledge base for future natural resources management decisions. The past and present direction of the City of Chattanooga Water Quality Program is to continuously gather information on the state of stormwater quality, patterns, and processes. This understanding is being approached through various activities including inspections, investigations (including needed enforcement activities), frequent monitoring, and master planning. The capacity to properly monitor the environment has decreased however in recent decades because of the increasing complexity of environmental conditions and processes. A mere status inventory of current water parameters may motivate the effort, without much communication of results to the appropriate parties. Such monitoring in the absence of clear objectives and with loose frameworks can often lead to the uncontrolled desire to collect more data, without pausing to visualize the results or trends associated.

Appropriate monitoring campaigns will help programs analyze trends, determine fate and transport of pollutants, define critical areas, assess compliance, and evaluate program effectiveness, among others. Even during the research and planning stages, data could be used to calibrate and refine planning tools, such as pollutant loading models. The success of such efforts should eventually reduce the need for costly water quality monitoring in the future. This direction will be further enhanced by proactive communication among different departments within city and county staff. If water quality research and ultimately improvements are the goal of municipal watershed management, then communications between like agencies must not be strained.

Additionally, program-related monitoring should focus on methods that better relate to results-relevant and results-driven water quality standards, as introduced in EPAs (2002) Twenty Needs Report. The monitoring goal of a sampling network is not only focused on detecting unusual pollution events, but also on monitoring the pollution distribution and temporal trend. Those responsible for monitoring should identify the goals and objectives for monitoring as well as the methods to be used for analyzing the collected data. It must be determined if the monitoring objectives are to monitor a water quality problem, or rather a symptom. As stated by Ward and colleagues (1986), appropriate designs of monitoring systems are needed to prevent a "data rich, but information poor" monitoring system. To make the most informed decisions for the water quality trends based on the obtained results, additional multi-factor analysis to evaluate the patterns and processes is desirable. Such *post-hoc* analysis will likely result in enhanced monitoring frameworks, locations, and practices, thereby increasing the effectiveness of the monitoring program.

Finally, public awareness will come from a comprehensive education program with the goal of encouraging citizens to make a positive impact on the quality of Chattanooga's water resources. Although City of Chattanooga stormwater personnel tend to excel in watershed planning, issue identification, and technical monitoring strategies, the inclusion of an active citizenry will likely achieve public change. Local citizens are seen as essential participants in collaborative environmental management because they can provide vital information about the area's natural and sociopolitical systems, as well as provide active support. If citizens are expected to exhibit concern over water resources and support preservation and restoration efforts, they must be engaged through a planned, long-term outreach program.

Many locally organized efforts have been undertaken as education and outreach programs and events to watershed groups and general population to increase awareness and knowledge about watershed and water quality issues. To the extent that such efforts increase knowledge about natural resources, they often increase communication and active participation as well. A watershed management plan should include narratives and plans on how to promote open communication, sufficient technical support, and fostering group participants' agreement on watershed priorities and how to address them. A watershed coordinator who can cultivate these factors among public outreach campaigns, and be willing to update the campaign as water quality issues and audiences change, may see more active public involvement.

As the Water Quality Program begins to identify and understand the trends in the various program aspects, it is refining those activities to maximize effectiveness. Initiatives are underway to adaptively manage the program in order to focus and intensify attention to previously unidentified stormwater quality problems and reduce attention to issues that have yielded little, if any, protection or enhancement of stormwater quality. By evaluating the effectiveness of these programs, staff and officials may be better informed about public response and success of these programs, how to improve the programs and which programs to (dis)continue. Such concentrated efforts on water quality will result in improved quality of water resources for the City of Chattanooga.

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